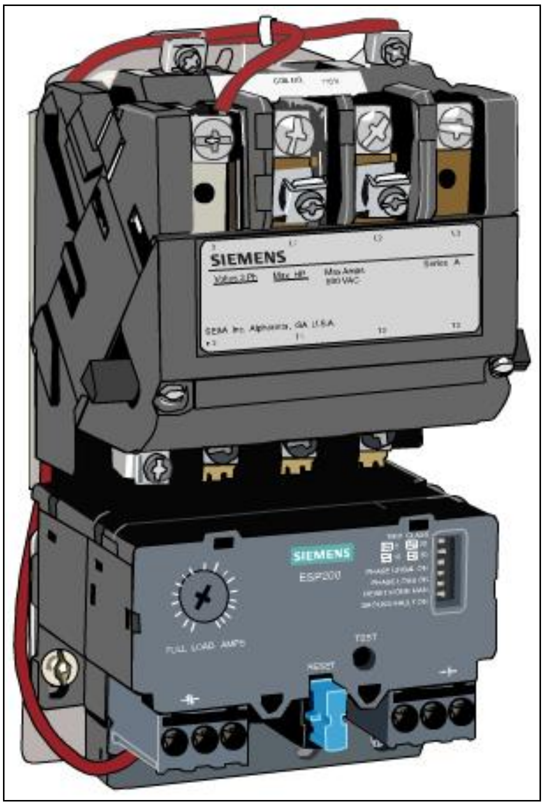


POWER SYSTEM PROTECTION AND CONTROL
STAGE 1D- BSP102

TEXTBOOK/WORKBOOK

POWER SYSTEM PROTECTION AND CONTROL

STAGE 1D- BSP102

Textbook/Workbook

TABLE OF CONTENTS

POWER SYSTEM PROTECTION AND CONTROL

STAGE 1D- BSP102

Textbook/Workbook

COURSE OVERVIEW

OVERVIEW

Power system protection and control stage (1D- BSP102) introduces theoretical concepts and workshop practices required to develop knowledge and hand skills of trainees for safe use of electrical equipment/instruments.

OBJECTIVES

Upon completion of this course, the trainees will be able to:

- Apply knowledge and skills to operate and maintain the AC/DC motors.
- Explain the purpose and applications of the transformer.
- Identify semiconductor applications.
- Identify the different types of transistors.
- Understand the operation of an oscillator.
- Identify electrical power system components.

CONTENT

This course has four (4) units of instruction with eight (8) lessons.

Unit 1: Motor Control Fundamentals

Unit 2: Transformers

Unit 3: Semiconductor Fundamentals

Unit 4: Introduction to Power Sources and Sec Network

DURATION

The course is designed for one hundred (100) hours that is divided into theoretical and practical instruction.

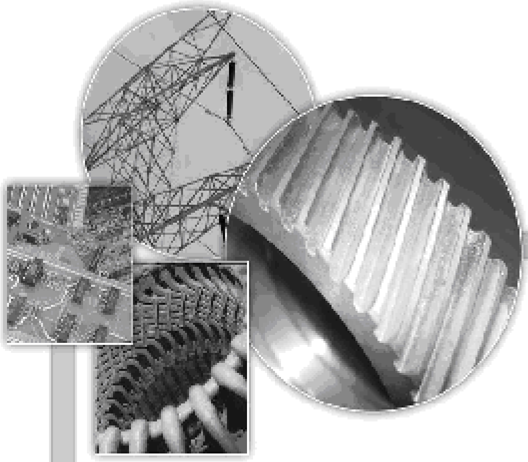
POWER SYSTEM PROTECTION AND CONTROL

STAGE 1D- BSP102

Textbook/Workbook

PACING SCHEDULE

Unit	Description	Duration (hours)
1	Motor control fundamentals	26
2	Transformers	12
3	Semiconductor Fundamentals	49
4	Introduction to Power system and Protective Equipment	8
	Review	5
	TOTAL	**100**



UNIT 1

MOTOR CONTROL FUNDAMENTALS

UNIT-1
MOTOR CONTROL FUNDAMENTALS

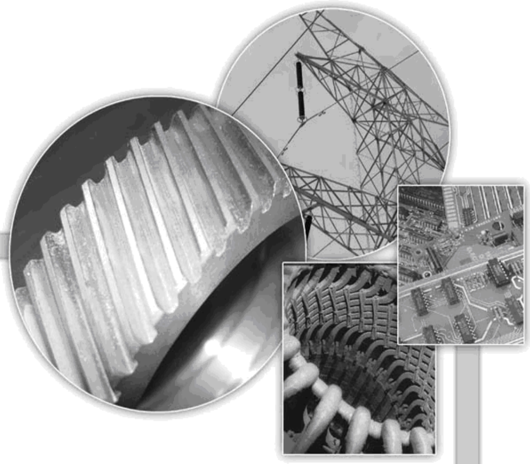
OVERVIEW

In this unit for motor control fundamentals, the trainees learn the construction, operation, types of AC/DC motors how to control AC/DC motors.

OBJECTIVES

Upon completion of this unit, the trainees will be able to:

- Apply knowledge and skills to operate and maintenance of the AC/DC motors.
- Apply knowledge and skills to operate and maintenance control circuits for the AC/DC motors.



LESSON 1.1

MOTORS

LESSON 1.1
MOTORS

OVERVIEW

This lesson discusses the fundamental construction and operation of different types of AC/DC motors emphasizing more on single and three phase AC motors.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Describe the basic construction of DC motors.
- List the principle of operations of DC motors.
- State the different types of DC motors.
- Describe the basic construction of single and three phase induction motors.
- List the principle of operations of wound rotor induction motors.
- Describe the basic construction of three phase synchronous motor.

INTRODUCTION

Motors play an important part in the industrial environment, and should therefore be of interest to the electrician.

Motors are divided into two types: direct current (DC motors) and alternating current (AC motors). Each of these categories is further divided into different types, as shown in Fig. 1.1-1.

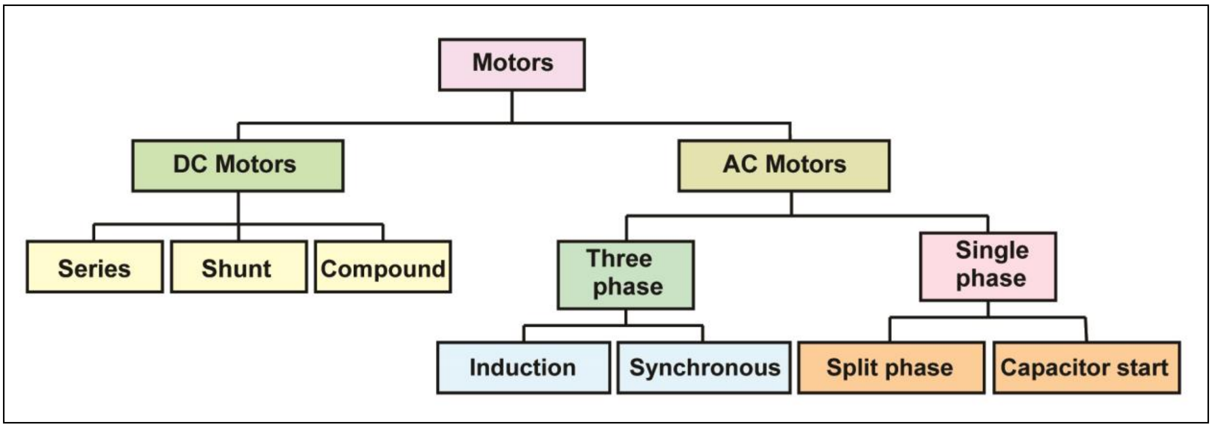


Fig. 1.1-1 Types of Motors

DC MOTORS

The direct current (DC) motor is one of the first machines devised to convert electrical power into mechanical power. Permanent magnet (PM) direct current convert electrical energy into mechanical energy through the interaction of two magnetic fields. One field is produced by a permanent magnet, the other field is produced by an electrical current flowing in the motor windings (Fig. 1.1-2). These two fields result in a torque which tends to rotate the rotor.

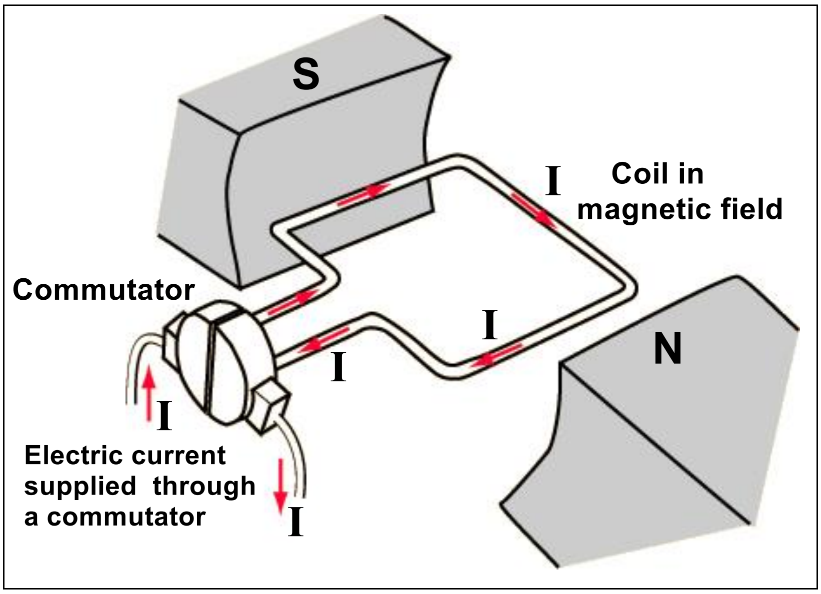


Fig. 1.1-2 Principle of Operation of DC Motor

PRACTICAL DC MOTORS

Practical DC motors are constructed, as shown in Fig. 1.1-3. All DC motors contain a field winding wound on pole pieces attached to a steel yoke.

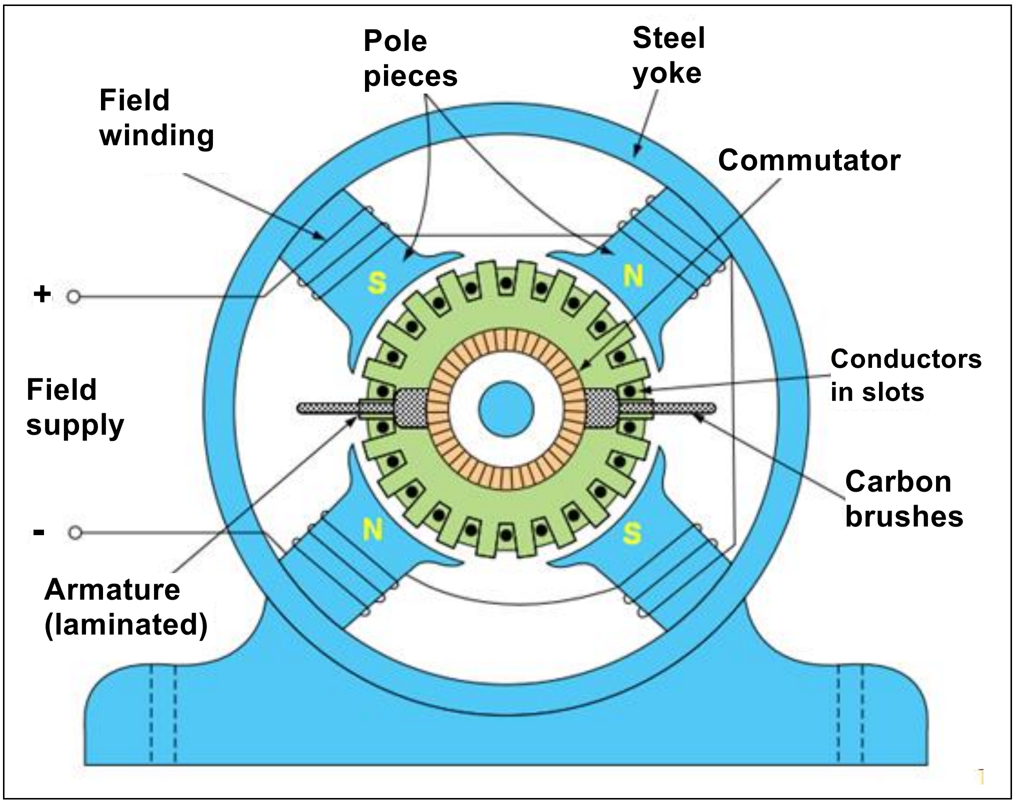


Fig. 1.1-3 D C. Machine Construction

The armature winding rotates between the poles and is connected to the commutator, as shown in Fig. 1.1-4. Contact with the external circuit is made through carbon brushes seated on the commutator segments.

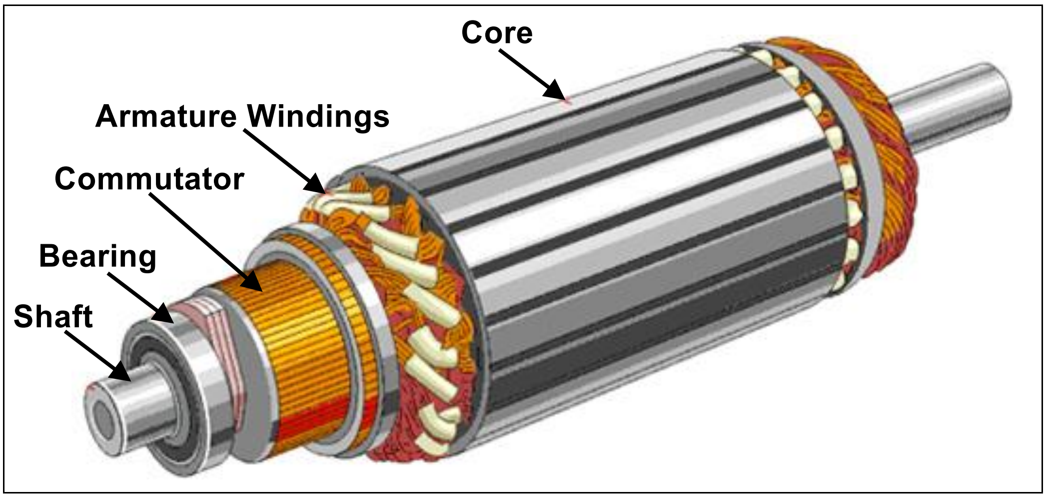


Fig. 1.1-4 Rotor Construction

TYPES OF DC MOTORS

Direct current motors are classified by the way in which the field and armature windings are connected, which may be in series, in shunt or in compound.

The selection of the proper type of a motor is based on the type of load that the motor is intended to operate (Fig. 1.1-5).

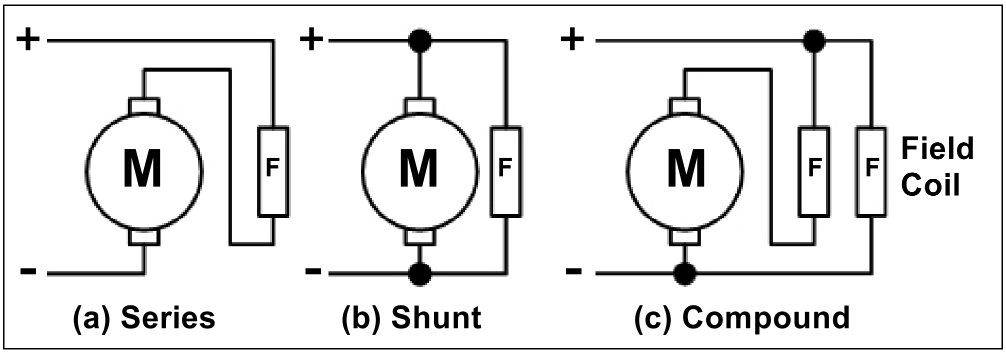


Fig. 1.1-5 Types of DC Motors

SERIES MOTORS

In series motors the field winding is connected in series with the armature, as shown in Fig. 1.1-5(a). The field is wound with large wire, since it carries the full armature current. Because of the higher current, only a few turns are necessary.

Series motors develop large amounts of starting torque. However, speed varies widely between no load and full load. Therefore, these motors cannot be used where a constant speed is required with variable loads. Additionally, **the speed of a series motor with no load can increase to the point of damaging the motor**. For this reason a series-motors is not generally suitable for use with variable speed drives.

SHUNT MOTORS

In a shunt motor the field is connected in parallel with the armature windings, as shown in Fig. 1.1-5(b). The shunt-connected motor offers **good speed regulation**. The field winding can be separately excited or connected to the same voltage source as the armature. An advantage to separately exciting the shunt field is that a variable speed drive can be used to provide independent control of field and armature.

COMPOUND MOTORS

Compound motors, as shown in Fig. 1.1-5(c), have a series-connected field winding and a separately excited shunt field. **The series field provides good starting torque, while the shunt field allows better speed regulation**.

DC MOTOR RATINGS

DC motors are rated according to their voltage, current, speed and horsepower output. Fig. 1.1-6 shows a typical DC motor nameplate.

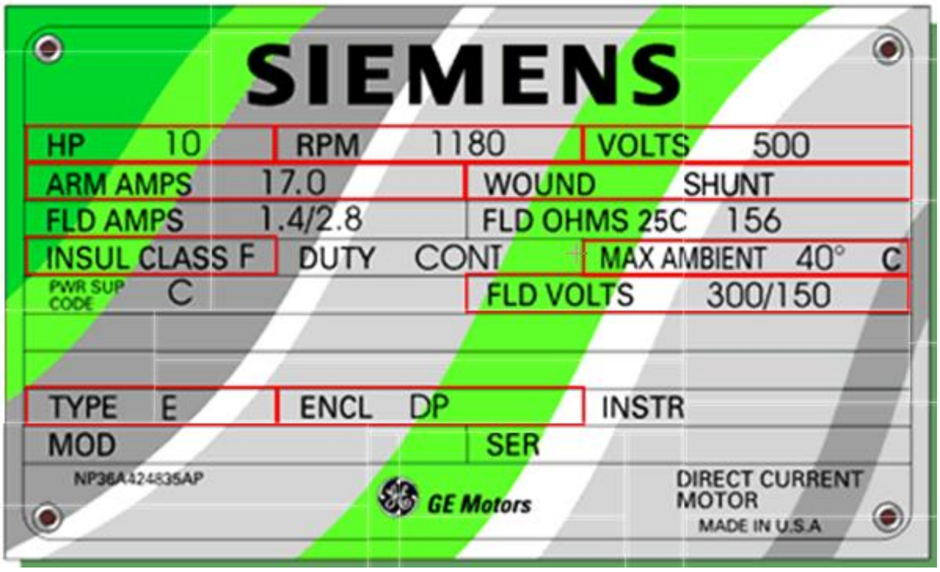


Fig. 1.1-6 Typical DC Motor Nameplate

DIRECTION OF ROTATION

Reversal of rotation of DC motors may be achieved by reversing the connections of either the field or armature windings but not both.

COMPARISON BETWEEN MAIN CHARACTERISTICS OF DC MOTORS

Type	Characteristics
Shunt	Good speed regulation
Series	Large amounts of starting torque The speed with no load can increase to the point of damaging the motor
Cumulative Compound	The series field provides good starting torque, while the shunt field allows better speed regulation

Table 1.1-1

ALTERNATING CURRENT MOTORS

Like DC motors, AC motors also have certain advantages that make them popular in industrial use. Basically, there are three types of three phase AC motors commonly used. They are the three-phase squirrel-cage induction motor, three phase wound rotor motor and synchronous motor.

THREE-PHASE INDUCTION MOTORS

The three-phase induction motor (Fig. 1.1-7) is one of the most widely used for industrial applications. It is relatively small in size for a given horsepower rating as compared to other types. It has a good speed regulation under varying load conditions.

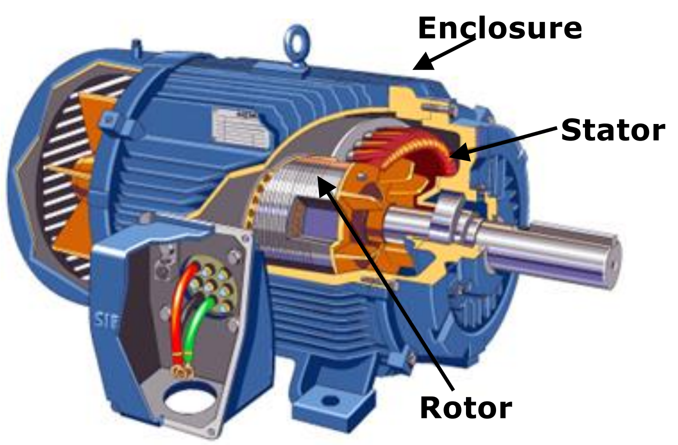


Fig. 1.1-7 Three-Phase Induction Motors

ROTOR CONSTRUCTION

There are two types of induction motor rotor: cage rotor and wound rotor.

SQUIRREL-CAGE INDUCTION MOTOR

The cage rotor consists of a laminated cylinder of silicon steel with copper or aluminium bars slotted in holes around the circumference and short circuited at each end of the cylinder (Fig. 1.1-8). Fig. 1.1-9 shows a connection of a three-phase squirrel-cage induction motor.

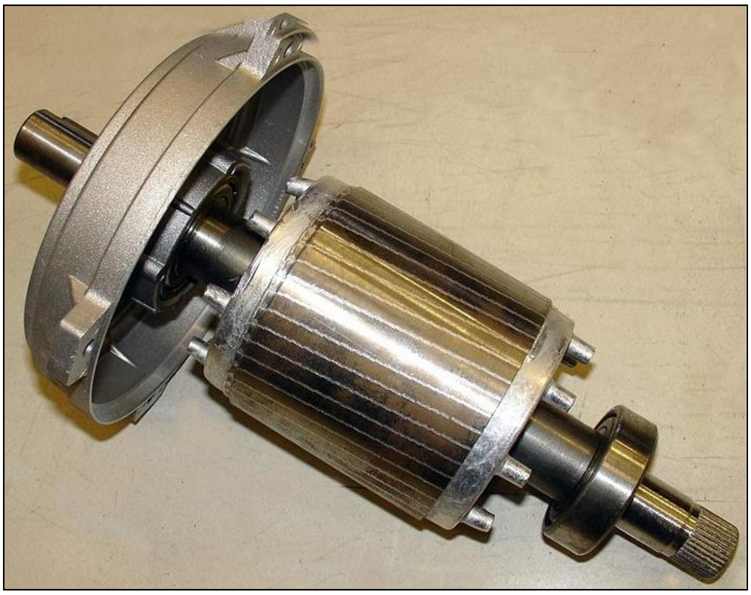


Fig. 1.1-8 Squirrel Cage Rotor

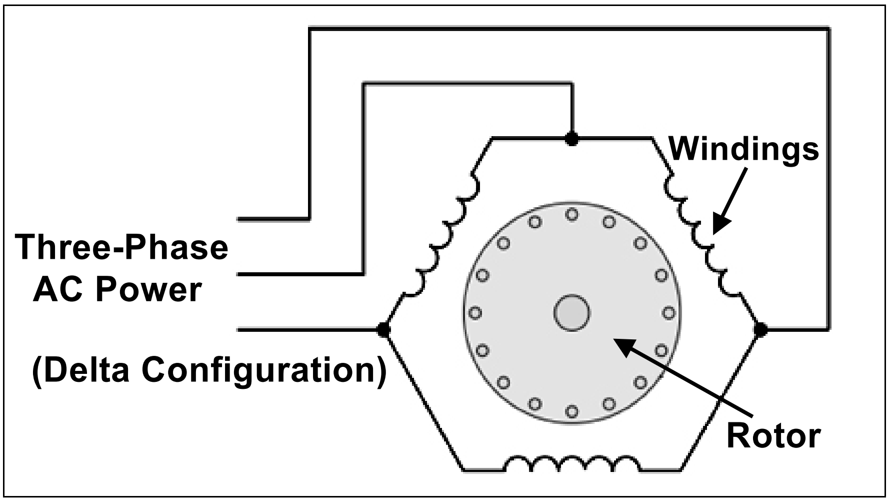


Fig. 1.1-9 A Three-Phase Squirrel-Cage Induction Motor Connection

The cage induction motor has a small starting torque and should be used with light loads or started with the load disconnected. The speed is almost constant. Its applications are for constant speed machines such as fans and pumps. Reversal of rotation is achieved by reversing any two of the stator winding connections.

WOUND ROTOR INDUCTION MOTOR

Another type of three-phase induction motor is the wound rotor motor. The major difference between the wound rotor motor and the squirrel cage rotor is that the conductors of the wound rotor consist of wound coils instead of bars (Fig. 1.1-10).

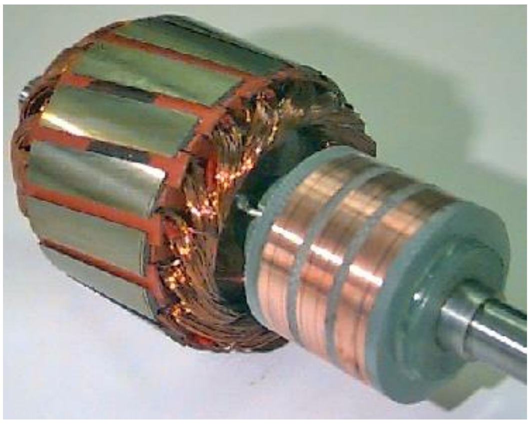


Fig. 1.1-10 Wound Rotor

The windings may be connected in star (Fig. 1.1-11) or delta and the end connections brought out to slip rings mounted on the shaft. Connection by carbon brushes can then be made to variable resistors to improve starting.

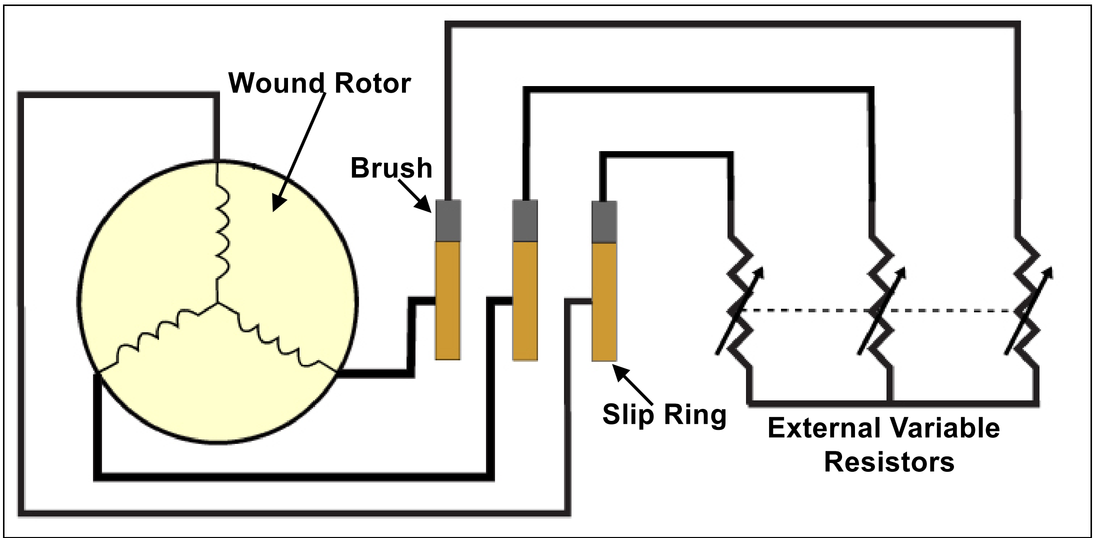


Fig. 1.1-11 Connections of Wound Rotor

SPEED CONTROL

When a three-phase current is applied to the three single-phase windings of the stator field, a rotating magnetic field is established inside the stator core. The speed of this

rotating field depends on the frequency of the applied current and the number of poles of the field windings. This speed is called synchronous speed and can be determined by:

$$N_S = \frac{120 \text{ X } f}{P} \quad \text{RPM}$$

Where: **f** = Power frequency (60 Hz) **P** = No. of poles

As the speed of the three-phase induction motor depends on the synchronous speed of the applied voltage and the number of poles of the motor, therefore, this type of motor has virtually no speed control. Therefore, these motors are used in applications where speed remains constant or where it can be controlled by other means such as variable speed drives.

The rotating magnetic field of wound rotor induction motor induces a voltage in the rotor windings. Increasing the resistance of the rotor windings causes less current to flow in the rotor windings, decreasing rotor speed. Decreasing the resistance causes more current to flow, increasing rotor speed.

SLIP

The rotor in a three-phase induction motor always turns at a speed (**N)** slightly less than a synchronous speed (**N_S**) to produce enough torque for starting the motor.

There must be a relative difference of speed between the rotor (**N**) and the synchronous speed (**N_S**). The difference in speed between the rotor and the synchronous speed is known as **Percent slip (S%)**.

$$S\% = \frac{N_S - N}{N_S} \times 100$$

EXAMPLE 3.1-1

A four-pole 60 Hz, three phase squirrel-cage induction motor has a full load speed of 1750 RPM. Determine the synchronous speed of this motor and the slip.

SOLUTION

f = 60 Hz P = 4 N = 1750 RPM

$$N_S = \frac{120 \ X \ f}{P} = \frac{120 \ X \ 60}{4} = 1800 \ \text{RPM}$$

$$S\% = \frac{N_S - N}{N_S} \times 100 = \frac{1800 - 1750}{1800} \times 100 = 2.8$$

MOTOR NAMEPLATE

The nameplate of a motor provides important information necessary for proper application. For example, Fig. 1.1-12 shows the nameplate of a 30 horsepower (HP.) three-phase (3 PH) AC motor. An AC motor is designed to operate at standard voltage. This motor is designed to be powered by a three-phase 460 V supply. Its rated full-load current is 35.0 amps.

Base speed is given in RPM, at which the motor develops rated horsepower at rated voltage and frequency. Base speed is an indication of how fast the output shaft will turn the connected equipment when fully loaded. This motor has a base speed of 1765 RPM at a rated frequency of 60 Hz.

Because the synchronous speed of a 4-pole motor operated at 60 Hz is 1800 RPM, the full-load slip in this case is 1.9%.

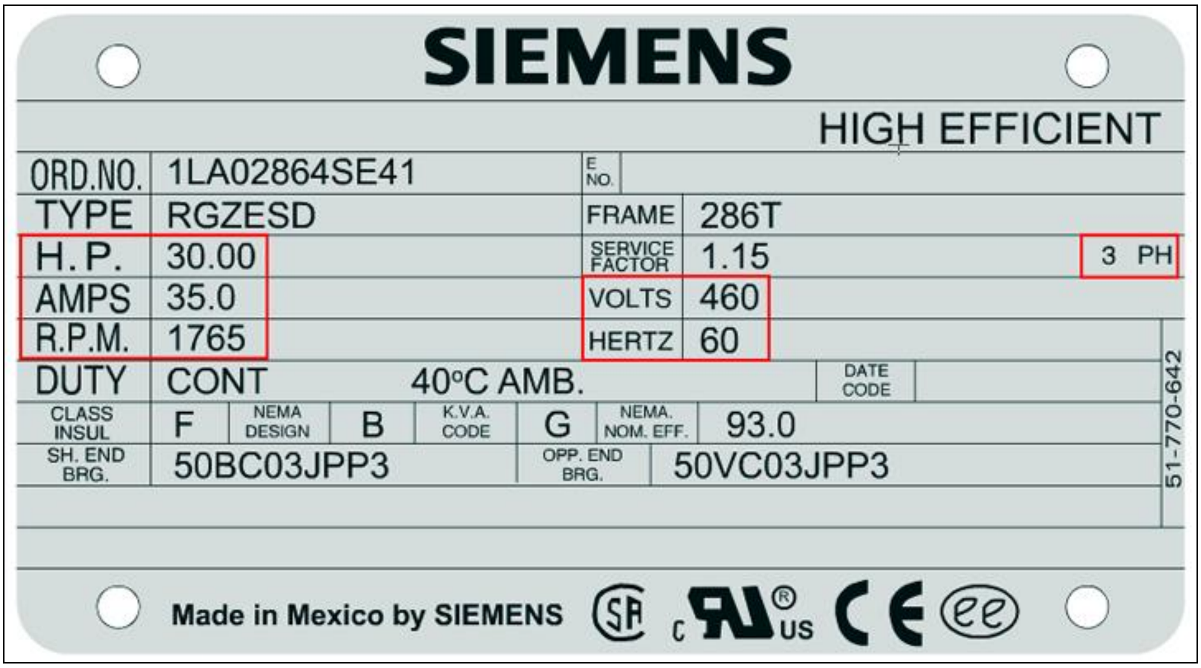


Fig. 1.1-12 Typical Induction Motor Nameplate

SYNCHRONOUS MOTOR

The synchronous motor (Fig. 1.1-13) is a three-phase motor, which operates at a constant speed from no load to full load. It is similar to a three-phase AC generator. That is, it has a rotating field, which must be separately excited, from a Direct Current (DC) source (Fig. 1.1-14). The DC field excitation current can be varied to obtain a wide range of lagging and leading power factor values.

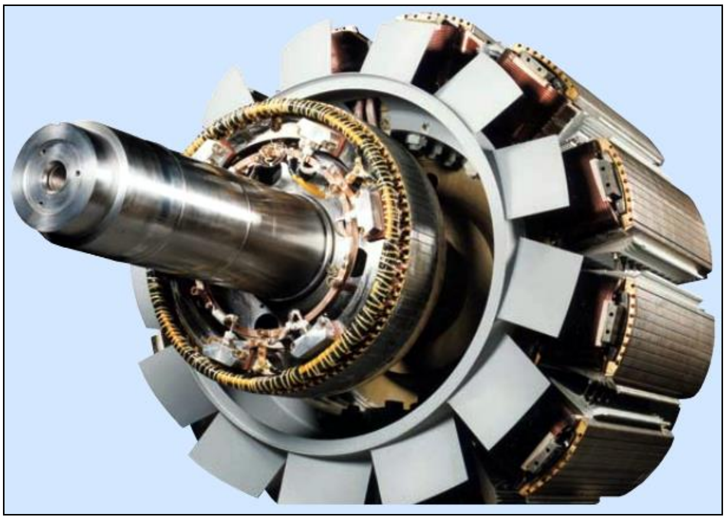


Fig. 1.1-13 Synchronous Motor

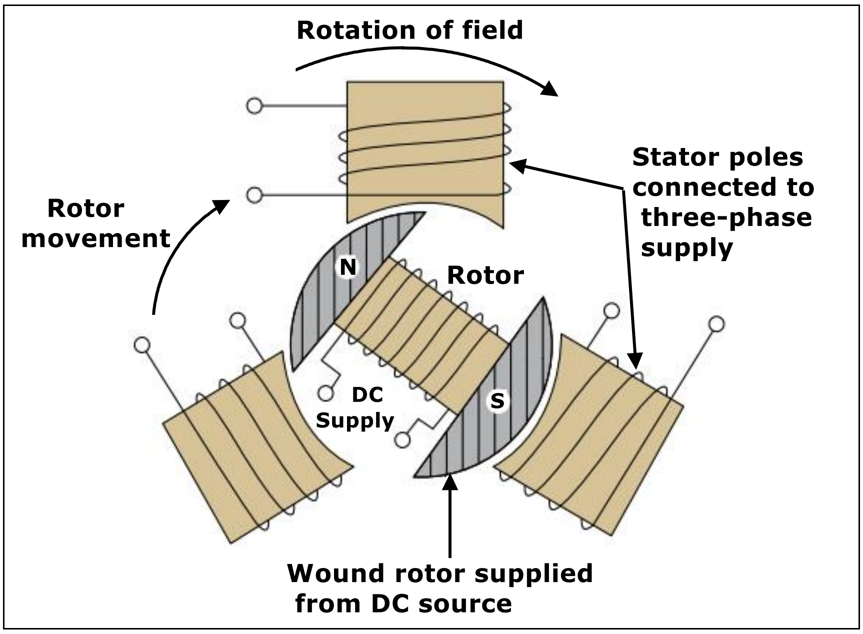


Fig. 1.1-14 External Connections of Synchronous Motor

APPLICATIONS FOR SYNCHRONOUS MOTORS

With constant-speed operation, power factor control, and high operating efficiency, three-phase synchronous motors are employed in a wide range of applications. An overexcited synchronous motor, known as a **synchronous condenser**, is used to improve the system power factor. Synchronous motors are used as prime movers of DC generators and variable-frequency ac generators. Typical applications include pumps, compressors, mills, mixers, and crushers.

SINGLE PHASE INDUCTION MOTORS

There are three principal types single-phase induction motors available, depending on the starting characteristics required for different applications.

SPLIT-PHASE MOTORS

Split-phase motors have two stator windings (a main winding and an auxiliary winding) with their axes displaced 90 electrical degrees in space. As represented in

Fig. 1.1-15, the auxiliary winding in this type of motor has a higher resistance-to-reactance ratio than the main winding. The rotating stator field produced by the unbalanced two-phase winding currents causes the motor to start.

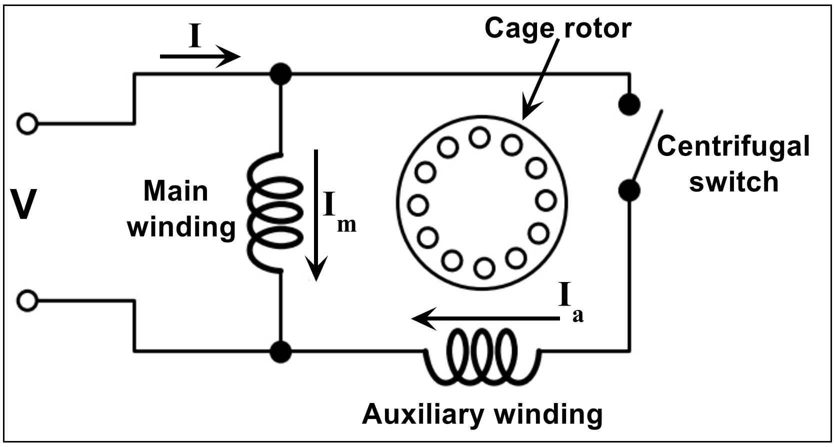


Fig. 1.1-15 Split-Phase Motor

The auxiliary winding is disconnected by a centrifugal switch or relay when the motor comes up to about **75%** of the synchronous speed. The torque-speed characteristic of the split-phase motor is shown in Fig. 1.1-16. A split-phase motor can develop a higher starting torque if a series resistance is inserted in the starting auxiliary winding. A similar effect can be obtained by inserting a series inductive reactance in the main winding; this additional reactance is short-circuited when the motor builds up speed.

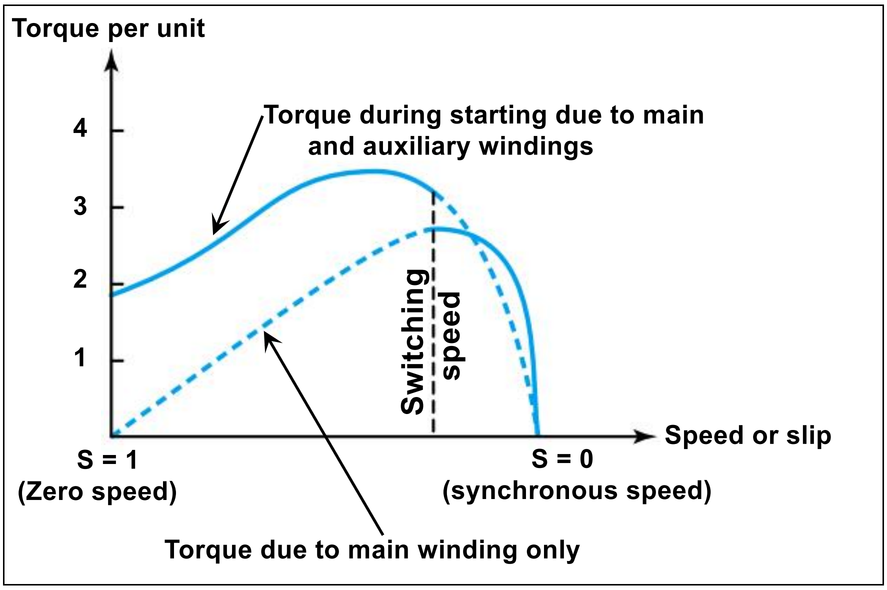


Fig. 1.1-16 Typical Torque-Speed or (Slip) Characteristic

CAPACITOR START MOTORS

Capacitor-start motors have a capacitor in series with the auxiliary winding available in three types:

- **Permanent-split capacitor-start motor** (Fig. 1.1-17)
- **Capacitor-start motor** (Fig. 1.1-18)
- **Capacitor-start-run motor** (Fig. 1.1-19)

As their names imply, the capacitor start and two-value capacitor use a centrifugal switch or relay to open the circuit or reduce the size of the starting capacitor when the motor comes up to speed.

A two-value-capacitor-start-run motor has one capacitor for starting and one for running the starting capacitor being disconnected after the motor starts, designed for optimum starting and running performance.

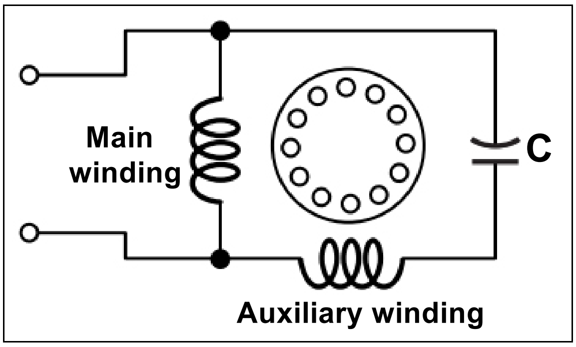


Fig. 1.1-17 Permanent-Split Capacitor

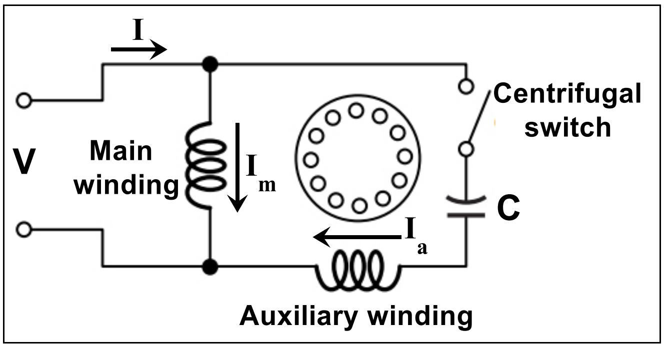


Fig. 1.1-18 Capacitor Start Motor

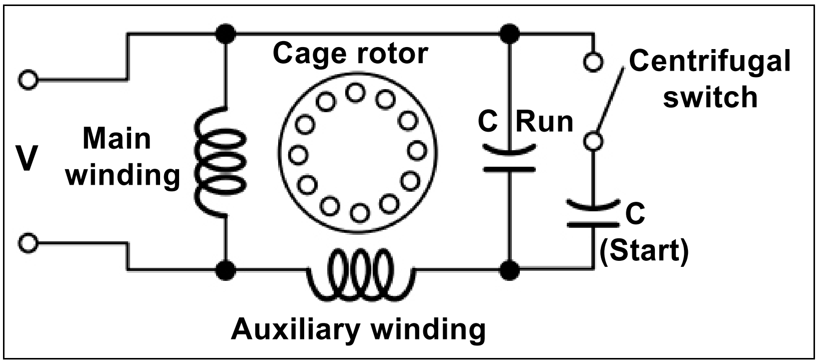


Fig. 1.1-19 Capacitor-Start-Run Motor

DIRECTION OF ROTATION

If it is necessary to reverse the rotation of the motor, simply interchange the leads of the starting winding. By interchanging the leads of the starting winding, the direction of the field setup by the stator windings is reversed. As a result, the direction of rotation of the rotor is changed.

APPLICATIONS FOR SINGLE-PHASE INDUCTION MOTORS

The single-phase induction motors are usually of fractional horsepower size. The split-phase motor is used to operate such devices as washing machines, small water pumps, oil burners and other relatively small loads, which do not require a strong starting torque.

The capacitor-start motor, on the other hand, can be used on devices, which do require a strong starting torque such as on refrigerators, compressors, and other types of load. Both types of single-phase induction motors are widely used because of their relatively low purchase cost, rugged construction and good operating performance.

UNIVERSAL MOTOR

The universal motor (Fig. 1.1-20) is a series-type motor that can operate on AC or DC. The rotor is a wound-rotor with commutator and brushes similar to a series DC motor.

This motor is used mainly in low-power applications such as fans, vacuum cleaners and electric drills. The principle of operation is similar to that of the DC series motor whether its input is **AC** or **DC**.

Torque is developed in one direction only, regardless of the direction of current flow through the series field and wound-rotor. To reverse direction, either the field or rotor current must be reversed.

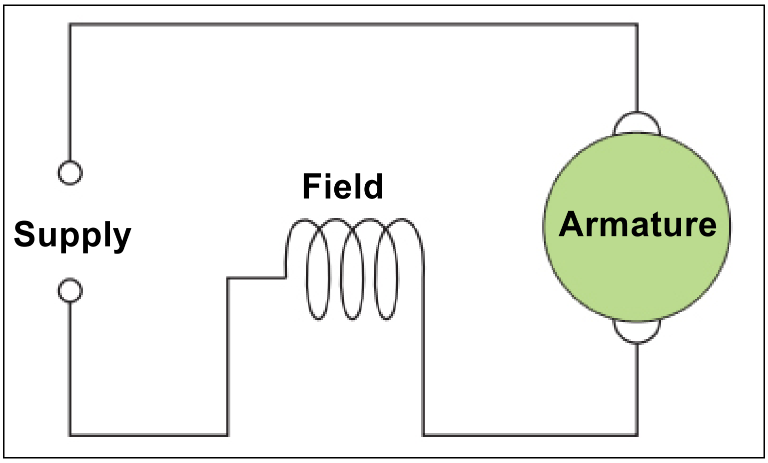


Fig. 1.1-20 Universal Motor

DIRECTION OF ROTATION

Changing the direction of the current in either the field or armature circuit can reverse the direction of rotation of any series-wound motor. Universal motors are sensitive to brush position and severe arcing at the brushes will result from changing the direction of rotation without shifting the brushes to the neutral (sparkless) plane.

SUNMMARY

- Direct current motors are classified by the way in which the field and armature windings are connected, which may be in series, in shunt or in compound.
- The shunt-connected motor offers good speed regulation.
- Compound motors have a series-connected field winding and a separately excited shunt field.
- Reversal of rotation of DC motors may be achieved by reversing the connections of either the field or armature windings but not both.
- There are two types of induction motor rotor - the cage rotor and the wound rotor.
- When a three-phase current is applied to the three single-phase windings of the stator field, a rotating magnetic field is established inside the stator core.
- The speed of this rotating field depends on the frequency of the applied current and the number of poles of the field windings.
- The difference in speed between the rotor and the rotating field is known as Percent slip (S%).
- The synchronous motor is a three-phase motor, which operates at a constant speed from no load to full load. It is similar to a three-phase AC generator.
- There are three principal types single-phase induction motors available, depending on the starting characteristics required for different applications.
- Split-phase motors have two stator windings (a main winding and an auxiliary winding) with their axes displaced 90 electrical degrees in space.
- Capacitor-start motors have a capacitor in series with the auxiliary winding are available in three types: capacitor start, two-value capacitor, and permanent-split capacitor.
- The universal motor is a series-type motor that can operate on AC or DC.

FORMULAS

$$N_S = \frac{120f}{P} \quad \text{RPM}$$

Where: f = Power frequency (60 Hz) P = No. of poles

$$S\% = \frac{N_S - N}{N_S} \times 100$$

Where: S% = Percent slip

N_S = Synchronous speed N = Rotor speed

GLOSSARY

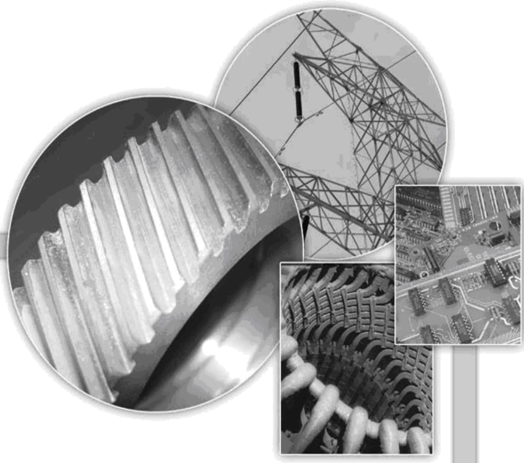
Motor (M)	A device that transforms electrical energy into mechanical energy
DC motor	A motor that converts direct current electrical energy into mechanical energy
AC motor	A motor that converts alternating current electrical energy into mechanical energy
Universal motor	a motor that can operate on AC or DC
Horsepower (HP)	A unit of power. 1 horsepower is equal to 746 watts
Slip (S%)	The difference between the synchronous speed of a three-phase induction motor and the rotor speed. Slip is often expressed as a percentage
Synchronous speed (N_S)	The speed of the rotating magnetic field in a three-phase motor
Enclosure	A motor protective housing

REVIEW EXERCISE

1. What is the speed of the rotating magnetic field of an eight-pole 60 Hz, three phase induction motor?
2. A six-pole 60 Hz, three phase squirrel-cage induction motor has a full load speed of 1150 rpm. Determine the synchronous speed of this motor and the slip.

FILL IN THE BLANKS:

3. The rotation of a three phase motor can be reversed by ____________ line leads.
4. The difference between the speed of rotating magnetic field of the stator and the speed of the rotor is called the ___________________.
5. An induction motor depends on a _______________ field for its operation.
6. In a DC series motor, the field winding is in ________ with the armature winding.
7. In a DC shunt motor, the field winding is in ________ with the armature winding.
8. The two principal types of single-phase induction motors are the ________ motor and the __________ motor.
9. The synchronous speed of an induction motor is the speed of the ___________ field.
10. Increasing the number of _______ of an induction motor, increases the rotating field.
11. An overexcited synchronous motor, known as a synchronous _______, is used to improve the system ___________.



LESSON 1.2

CONTROL CIRCUITS

LESSON 1.2
CONTROL CIRCUITS

OVERVEIW

This lesson gives in depth understanding of control circuits and control devices.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Define the different switch configurations.
- Describe normally closed and normally open contacts.
- Describe the features and operations of a general-purpose relay.
- Describe the main difference between an AC and DC relay.
- State the purpose and applications of a fast acting relay.
- Describe operation mechanisms of the different types of timer relays.

Task 1.2-1: Control Equipment

Task 1.2-2: Full Voltage Starter

SWITCH CONFIGURATIONS

A switch is a device, which when installed in a circuit, performs the function of turning ON and OFF the supply voltage to the load by making and breaking the circuit.

Three terms commonly used in the description of switch configurations are **pole**, **throw** and **break (**Fig. 1.2-1).

Pole: describes the number of isolated circuits that can be connected through the relay at one time. A **single-pole** circuit provides a path for current in one circuit at a time. A **double-pole** circuit provides paths for current in two circuits at a time with contacts that are mechanically interconnected in the switch so that both contacts open and close at the same time.

Throw: describes the number of different closed-contact positions per pole. This is the number of different circuits that each pole controls.

Break: describes the number of separate contact points used to open or close each circuit. If the circuit is broken at one point when the contacts open, it is a single break contact arrangement, but if two contact points are used, it is a double-break arrangement.

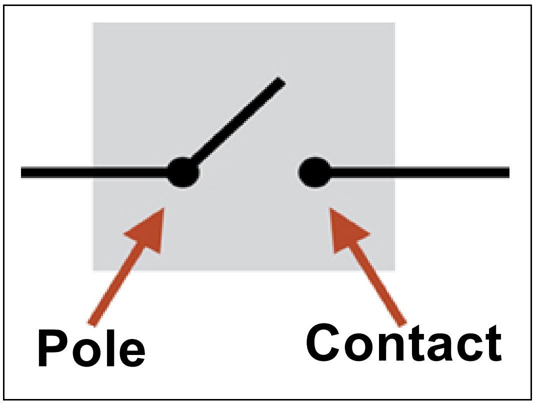


Fig. 1.2-1 Single Pole-Single Throw single break

Switches are made in various configurations, as follows:

Pole and **throw** contact arrangements are frequently abbreviated as follows:

SPST: single-pole, single-throw

SPDT: single-pole, double-throw

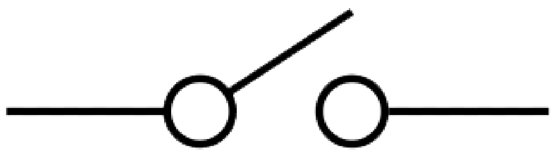
DPST: double-pole, single-throw

DPDT: double-pole, double-throw

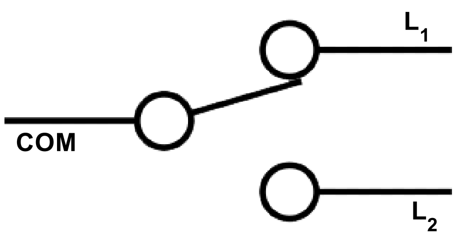
In each of the above configuration, there are two types of designs:

- Single Break
- Double Break

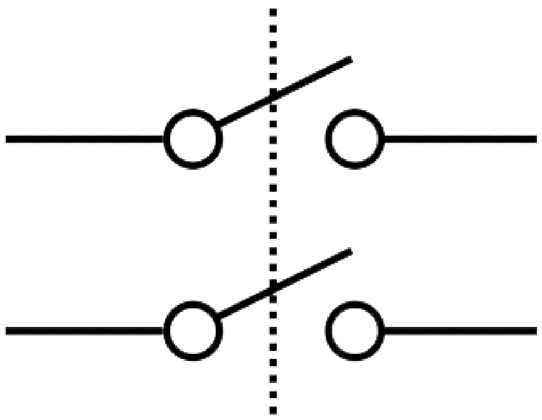
SINGLE-POLE-SINGLE-THROW - SINGLE BREAK (SPST)

Single Pole-Single Throw single break switch has only one pole. In the **ON** position, it makes the contacts for only one circuit. To switch **OFF** a circuit, the single pole breaks the contact and moves to its **OFF** position. The symbol for **SPST** single break switch is given in Fig. 1.2-2.	 Fig. 1.2-2 SPST - **Single** Break Switch

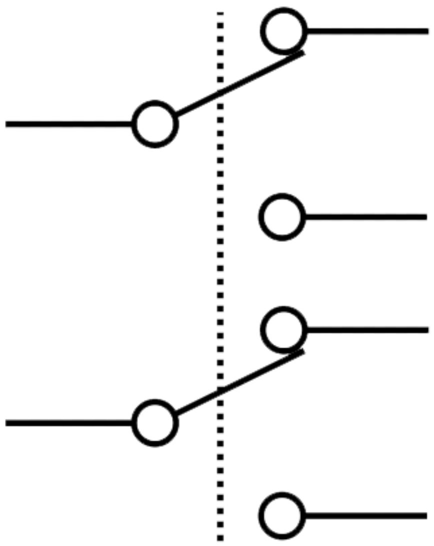
SINGLE POLE - DOUBLE THROW - SINGLE BREAK (SPDT)

A **SPDT**-single break switch has one pole. The pole makes contacts with one of the two terminals in one position and with the other terminal in the other position. The pole, while closing one circuit, opens the other. Fig. 1.2-3 shows the symbolic diagram of a SPDT-single break switch. A SPDT switch can be used as a selector switch.	 Fig. 1.2-3 SPDT - Single Break Switch

DOUBLE POLE - SINGLE THROW - SINGLE BREAK (DPST)

A **DPST**-single break switch (Fig. 1.2-4) has two poles that are ganged together each making or breaking together for two independent circuits. In one position, the two poles make contacts with a pair of terminals and in the other position the two poles open the contacts. This switch is used in circuits where a pair of lines is to be switched **ON** or **OFF** together, such as line and neutral for 1ϕ circuits (110VAC) or phase 1 and 2 for 3ϕ circuits (220VAC).	 Fig. 1.2-4 DPST - Single Break Switch

DOUBLE POLE - DOUBLE THROW - SINGLE BREAK

A **DPDT**-single break switch (Fig. 1.2-5) has two poles that are ganged together each making or breaking together for two independent circuits at two positions. In one position, the two poles make contacts with one pair of terminals for two independent circuits and in the other position, the two poles make contacts with another pair of terminals for another two independent circuits.	 Fig. 1.2-5 DPDT - Single Break Switch

DOUBLE BREAK SWITCHES

Fig. 1.2-6 shows a SPST switch - double break arrangement. The contacts make and break at two points, simultaneously. Double break contacts are capable of making and breaking larger currents compared to single break contacts of the same size.

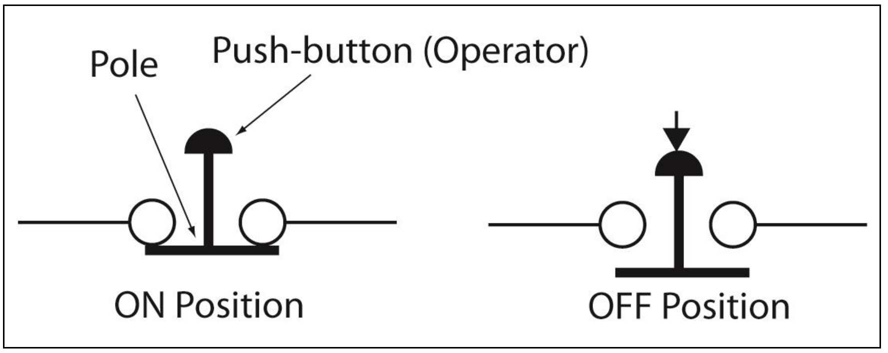
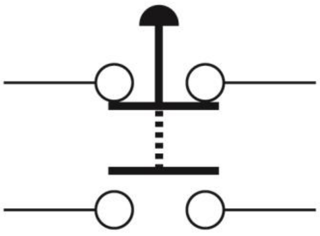


Fig. 1.2-6 Double Break Switch

Like in single-break switches, there are many configurations in double break switches:

- SPST
- SPDT
- DPST
- DPDT

Fig. 1.2-7 shows a Push-button switch with two contacts; one set of contacts is closed and the other is open. When the button is pressed, the closed contacts open and the open contacts close.	 Fig. 1.2-7 Double Break Double Contact Switch

MOTOR CONTROL CIRCUITS

Fig. 1.2-8 shows the schematic diagram of the control circuit of a motor starting circuit.

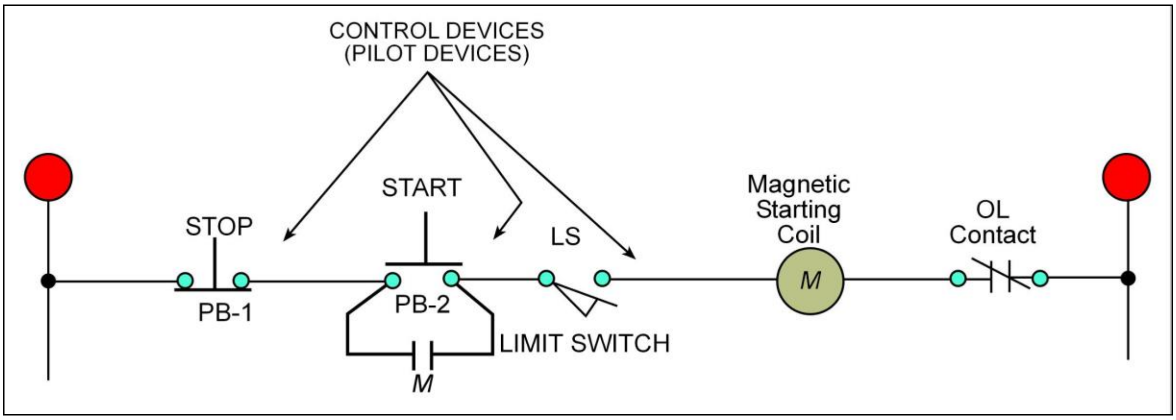


Fig. 1.2-8 Motor Control Circuit

The ‘**STOP**’ switch **PB-1** is a ‘Normally-Closed’ (**NC**) switch, which opens only when the button is pressed. The moment the finger is taken off, the contacts close again. The ‘**START**’ switch **PB-2** is a ‘Normally-Open’ (**NO**) switch. It closes only when the button is pressed. The moment the finger is taken off, the contacts open again. The ‘Limit Switch’ **(LS)** should be closed as a pre-condition for the motor to start. When **LS** is closed, if **PB-2**-switch is pressed, the **M** coil gets energized.

The **M** contacts bridge the **PB-2** contacts and maintain the **M** coil energized. The **M** coil can be de-energized by pressing **PB-1**-switch. When **PB-1**-switch is pressed the circuit is interrupted, the **M** coil gets de-energized, the **M** contacts drop out and the coil remains de-energized. For **LS**-switch to be closed, certain field condition should be satisfied; e.g., closing of a door. If **LS**-switch is open, the motor cannot be started. During running if the **LS**-switch opens for a failure of the field condition, the motor stops. In complex control circuits, several control devices are to be activated before a motor can be turned **ON**.

COIL

Coils are used in electromagnetic starters, contactors, and relays. Contactors, starters, and relays open or close contacts when energized. A letter is used in diagrams to designate the coil. The letter "**M**" frequently indicates a **motor starter**. "**CR**" used for

control relays. The associated contacts will have the same identifying letters, as shown in Fig. 1.2-9.

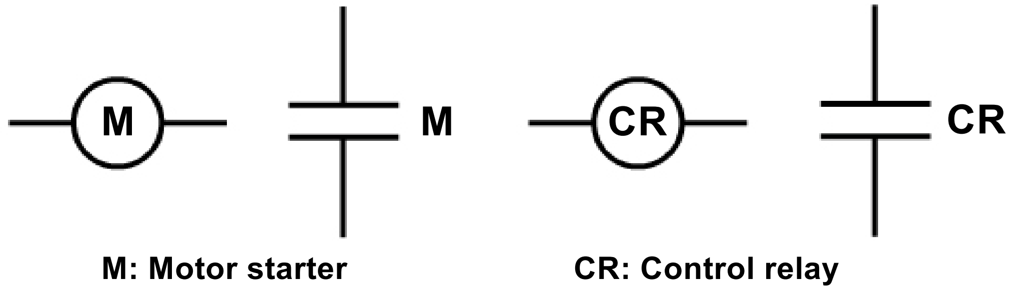
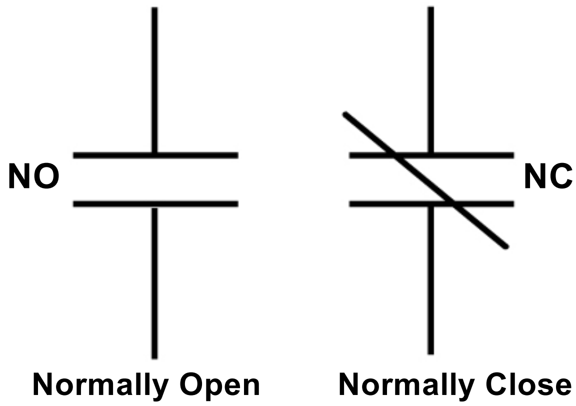


Fig. 1.2-9 Coil Symbols

CONTACTS

Contacts symbols (Fig. 1.2-10) are used to indicate an open or closed path for current flow. Contacts shown as normally open (NO) means that the contacts are open when the relay is de-energized. Normally closed (NC) means that the contacts are closed when the relay is de-energized.	 Fig. 1.2-10 Contacts Symbols

MOMENTARY AND MAINTAINED CONTACTS

Some switches, when pressed, remain in the pressed position. They do not need an external force to be held in that position. They are known as switches with maintained contacts. The status of the maintained contacts (CLOSED/OPEN) is changed every time the switch is operated. Because the contacts change status every time the switch is operated, it is also known as a **Toggle Switch**.

Some switches change the status of the contacts only as long as they are being pressed using an external force (finger). Once the force is withdrawn, the contacts return to their original position, by the operation of a spring or gravity. These types of switches are known to have **momentary contacts**.

CONTROL DEVICES

Control Devices are employed in motor control circuits to ensure that the desired pre-conditions are satisfied before starting a motor. If any one of the pre-conditions is not satisfied, the related control device prevents the contactor coil circuit from energizing.

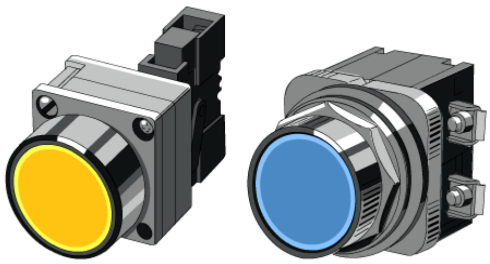
A control device is a '**control circuit element**' that changes its state in response to the changes in a physical condition (process parameter). Some of the process parameters are:

- Time
- Pressure
- Level
- Temperature
- Flow

The control devices are also known as **pilot devices**. A push-button is one type of pilot device. Push buttons are employed in control circuits to start and stop motors.
Some of the other pilot devices are:

- Limit Switch
- Pressure Switch
- Level Switch
- Temperature Switch
- Flow Switch

PUSH-BUTTON SWITCHES

A push-button (Fig. 1.2-11) is a control device used to manually open and close a set of contacts. Pushbuttons may be illuminated or non-illuminated and are available in a variety of configurations and actuator colors.	 Fig. 1.2-11 Push-Button Switches

SELECTOR SWITCHES

Selector switches (Fig. 1.2-12) are another means to manually open and close contacts and are commonly used to select one of two or more circuit possibilities.

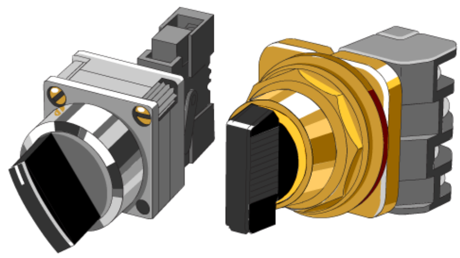


Fig. 1.2-12 Selector Switches

The basic difference between a pushbutton and a selector switch is the operator mechanism. A selector switch operator mechanism is rotated to open and close contacts.

Selector switches may be maintained, spring return, or key operated and are available in two-position, three-position, and four-position types.

THREE-POSITION SELECTOR SWITCH

A three-position selector switch can be used to select any one of three closed contact positions. In this illustration (Fig. 1.2-13), the selector switch has three positions (HAND, OFF, and AUTO) used to determine how contactor coil **M** for a pump motor can be energized.

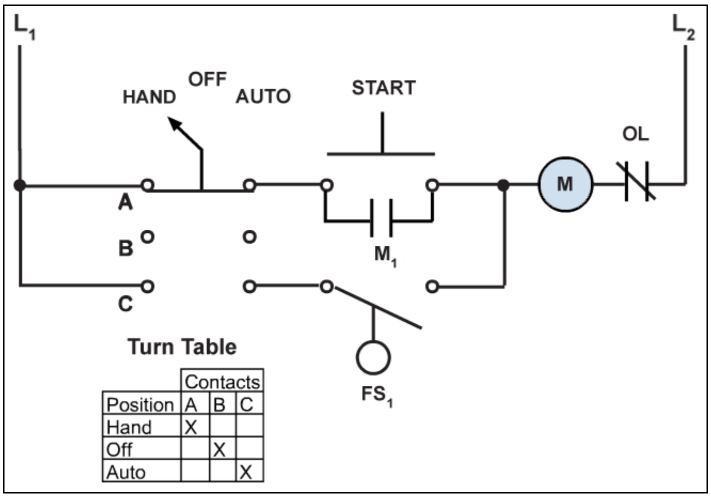


Fig. 1.2-13 Three-Position Selector Switch

With the selector switch in the OFF position, the **M** contactor coil cannot be energized because the selector switch contacts are in position **B**.

With the selector switch in the AUTO position, the **M** contactor coil will energize when the liquid level sensed by float switch **FS_1** rises sufficiently to close the circuit.

LIMIT SWITCHES

Limit switches (Fig. 1.2-14) are the most widely used pilot devices in motor control circuits in motion control applications, such as lifts and shutter doors.	 Fig. 1.2-14 Limit Switch

TEMPERATURE SWITCHES

Temperature switches (Fig. 1.2-15) are widely used in industrial applications. A temperature switch opens or closes its contacts to control the heaters when its sensor detects a preset temperature.

Fig. 1.2-15 Temperature Switches

PRESSURE SWITCHES

Pressure switches (Fig. 1.2-16) are used in a variety of motor control applications. A pressure switch opens or closes its contacts when its sensor detects preset pressure limit.

The applications include detecting high pressure, low pressure, differential pressure, and vacuum. Pressure switches are used as safety controls to protect systems from high or low pressure. It is also used as operational devices to cycle an air compressor to maintain constant pressure in a system.

Fig. 1.2-16 Pressure Switch

INDICATOR LAMPS

Indicator lamps (Fig. 1.2-17) are also considered pilot devices since they are located in the control portion of the circuit and because they draw a- low currents.

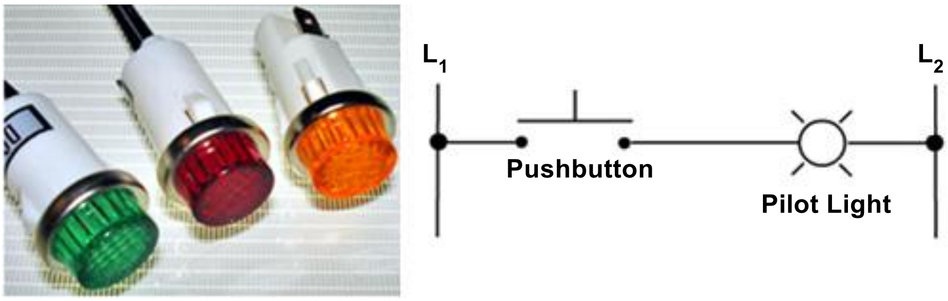


Fig. 1.2-17 Indicator Lamps

RELAYS

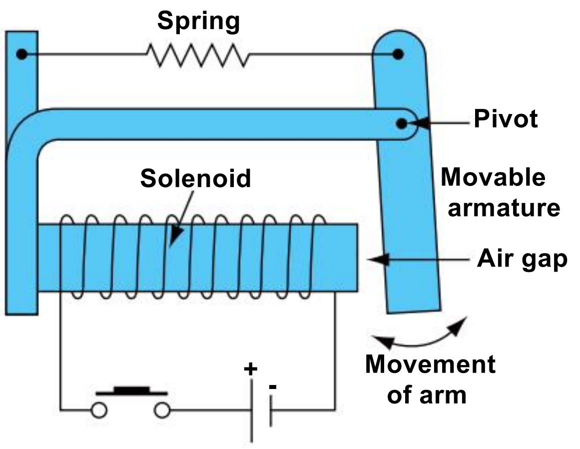
<table>
<tr>
<td>The relay (Fig. 1.2-18) uses solenoid operation to move a set of electrical contacts from the open to the closed position and vice versa. The basic principles involved in the operation of a relay are the same as those of a magnetic contactor.</td>
<td>

Fig. 1.2-18 Simple Relay</td>
</tr>
</table>

When the relay coil is energized, the magnetic field produces a force pulling the movable core (armature) into the center of the coil. When the coil is de-energized, the magnetic field is lost and the armature drops down to the original position by the operation of the gravity and/or a spring.

DC RELAYS

In DC relays (Fig. 1.2-19) the magnetic core is made of solid iron. The typical DC coil voltages are 6, 12, 24, 32, 48, 120 and 240 VDC. There is no coil inductance in DC application and the coil current is restricted only by its resistance. In order to maintain coil current at the required value, DC coils are made of wires of higher resistance.

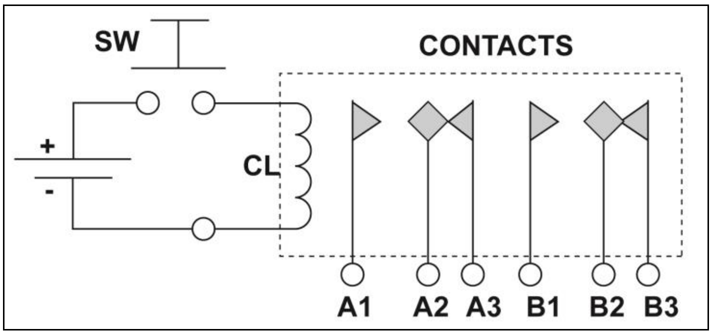


Fig. 1.2-19 24 Volt DC Relay

AC RELAYS

AC current induces an eddy current in the magnetic core. To avoid eddy current, the core in an AC relay is made of laminations. The laminations are coated with a thin film of insulation stacked and riveted in the core. The armature of the coil is similarly laminated. Shading coils are used to prevent the relay chattering (vibrating). The typical ac coil voltages are: 6, 12, 24, 32, 48, 110-115, 120, 208, 220, 240, 277, 380, 440, 480, 550 and 6000 VAC (Fig. 1.2-20).

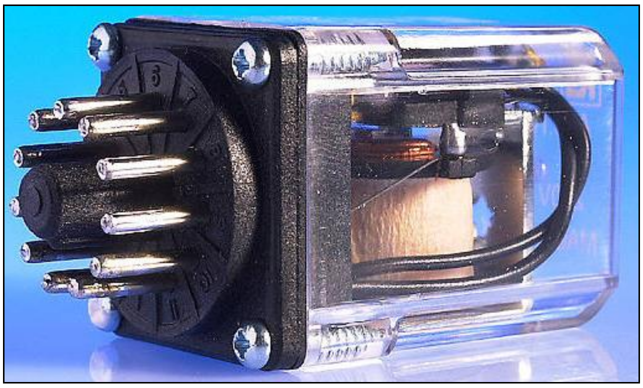


Fig. 1.2-20 230V 11 Pin Ac Relay 3 Pole

GENERAL PURPOSE RELAYS

Fig. 1.2-21 shows a general purpose socket mounted relay. The terminals of a socket are wired to the control circuit and the load circuits.

Fig. 1.2-21 General Purpose Relays

TIMER RELAYS

A timer relay has contacts to open or close with time delay after its coil is energized. These contacts are known as **time delay contacts**. The timer relay has also normal **NO** and **NC** contacts like a normal relay known as **instantaneous contacts** because they act instantaneously (immediately).

These relays are designed for two types of operation as follows:

ON-DELAY

Indicates that a timer will turn on and its contacts will change state a predetermined time after the timer receives a signal to turn on. An up arrow on a timer contact indicates that the contact is associated with an on-delay.

Fig. 1.2-22 shows on an on-delay, timed closed example. This configuration is also referred to as normally open, timed close (**NO TC**).

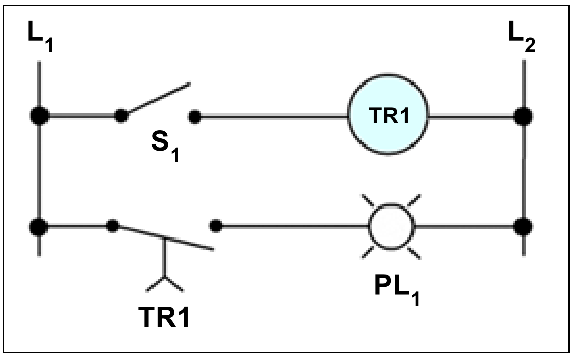


Fig. 1.2-22 Normally Open, Timed Close

OFF-DELAY

Means that a timer will turn off a predetermined time after the timer receives a signal to turn off. A down arrow on a timer contact indicates that the contact is associated with an off-delay.

Fig. 1.2-23 shows an off delay, timed open example. This configuration is also referred to as normally open, timed open (**NO TO**).

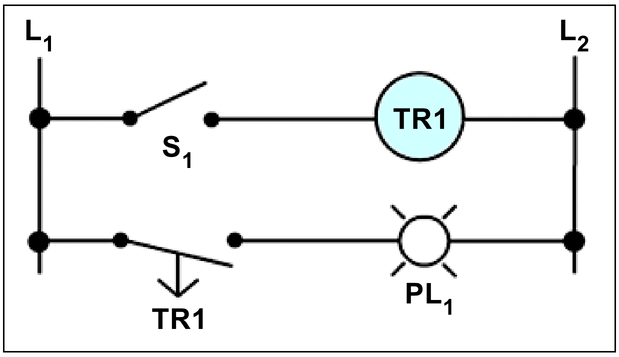


Fig. 1.2-23 Normally Open, Timed Open

There are different types of timer relays:

- Pneumatic (compressed air operated).
- Electro-mechanical.
- Thermal.
- Solid-state.

THERMAL TIME DELAY RELAYS

A thermal time-delay relay (Fig. 1.2-24) is constructed to produce a delayed action when energized. Its operation depends on the thermal action of a bimetallic element similar to that used in a thermal circuit breaker. A heater is mounted around or near the element. The movable contact is mounted on the element itself. As the heat causes the element to bend because of the different thermal expansion rates, the contacts close.

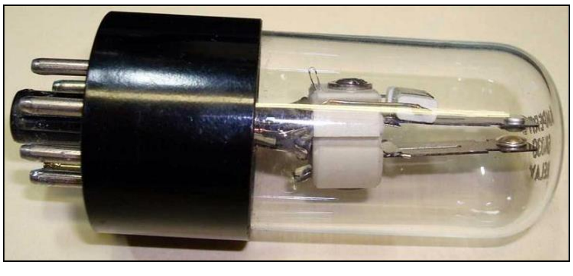


Fig. 1.2-24 Thermal Delay Relay

SOLID STATE TIMER RELAYS

A solid state timer relay provides high accuracy. It can be reset as quickly as 20 ms. A digital timer is fully programmable from a touch pad. Fig. 1.2-25 shows the circuit of a simple electronic timer relay. The circuit uses a variable resistor and a capacitor providing time delay circuit.

When the capacitor is charged, it fires the **UJT**. The **UJT** in turn switches the **SCR ON**. The time delay is adjustable through the variable resistor.

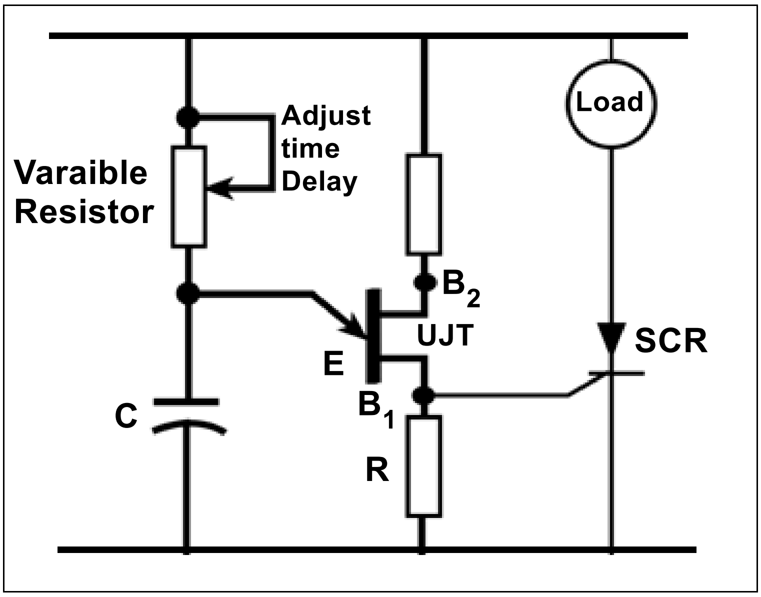


Fig. 1.2-25 Simple Electronic Timer Relay

BIMETAL OVERLOAD RELAYS

Overload protection can be provided by a bimetal overload relay (Fig. 1.2-26). This type of device consists of a small heater element wired in series with the motor and a bimetal strip that functions as a trip lever.

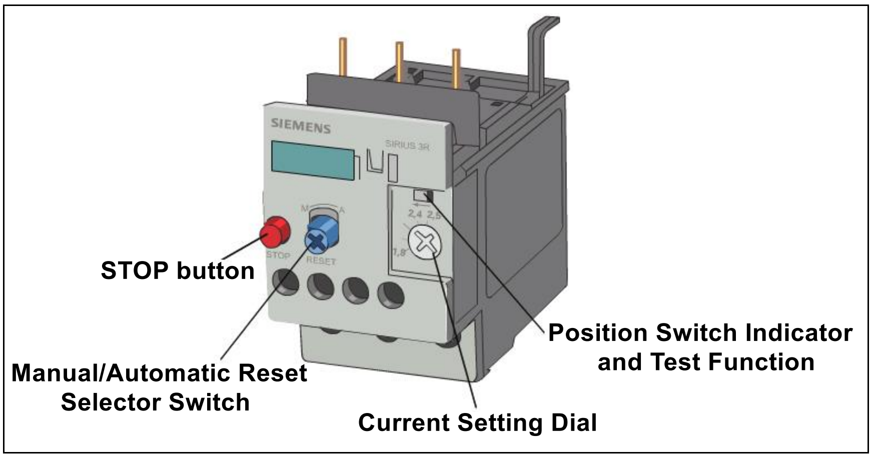


Fig. 1.2-26 Bimetal Overload Relay

The bimetal strip (Fig. 1.2-27) is made of two dissimilar metals bonded together. The two metals have different thermal expansion characteristics. As a result, the bimetal strip bends as it is heated.

Under normal conditions (Fig. 1.2-27), the heat generated by the heater element will bend the bimetal strip only slightly and the overload relay will not trip.

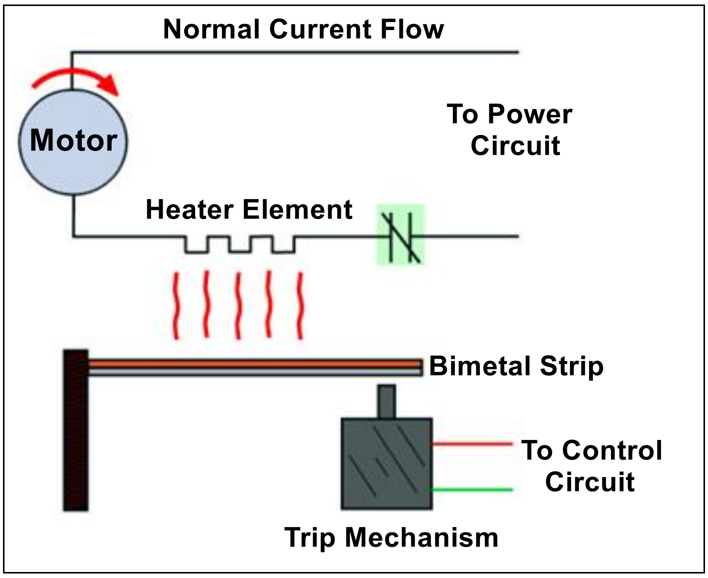


Fig. 1.2-27 Motor under Normal Conditions

As current rises, the heat from the heater element increases and the bimetal strip bends further (Fig. 1.2-28). If an overload condition persists, the heat from the heater will bend the bimetal strip sufficiently to trip the overload relay and stop the motor.

Some overload relays equipped with a bimetal strip are designed to reset the circuit automatically when the bimetal strip has cooled sufficiently and no longer activates the trip mechanism.

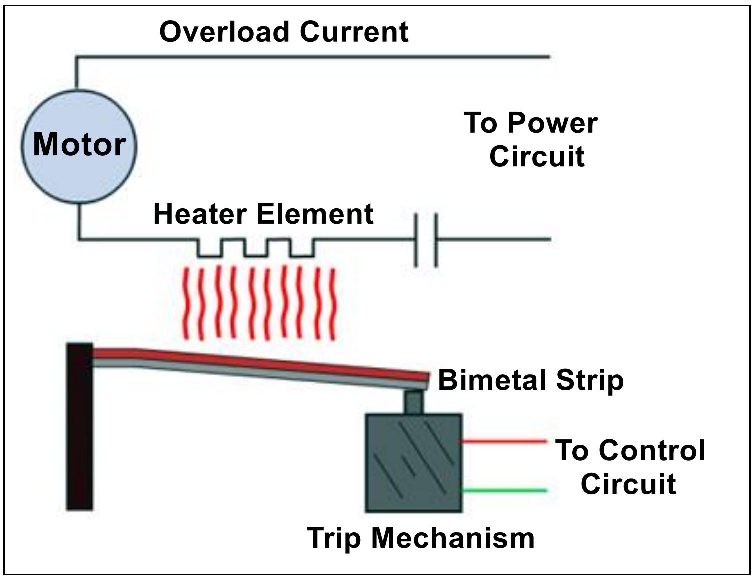


Fig. 1.2-28 Motor under Fault Conditions

BASIC CONTROL CIRCUIT

Fig. 1.2-29 shows a schematic for the basic control circuit having:

- One push button (**PB**)
- One control relay (**CR**)
- One Red indicating lamp (**R**)

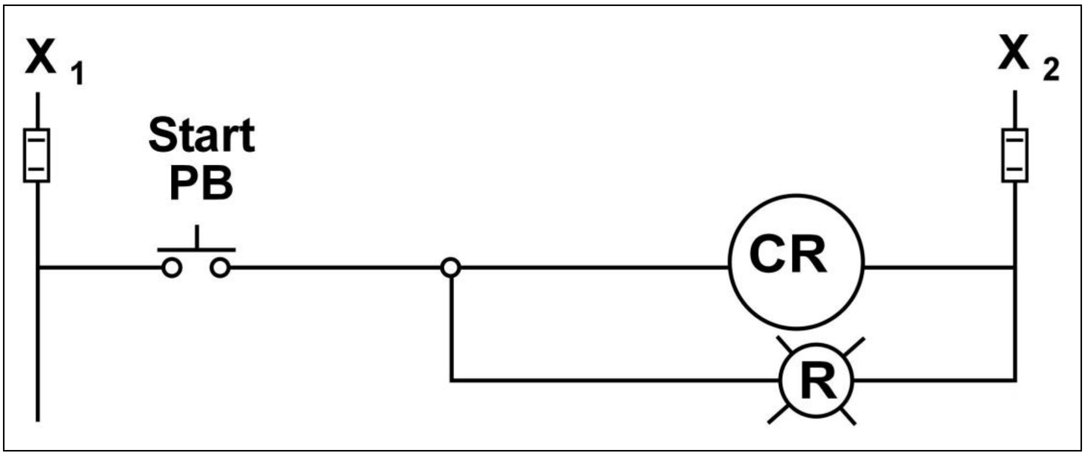


Fig. 1.2-29 Basic Control Circuit

BASIC CIRCUIT OPERATION

When PB is closed:

- **CR** is energized.
- Lamp **R** lights up
- When **PB** is released, **CR** de-energizes.
- Lamp **R** goes **OFF.**

HOLDING CIRCUIT

After you have installed and operated the basic control circuit, modify it to a **Holding Circuit**. A holding circuit maintains a path for current in the starting circuit, after the push button is released. The highlighted holding circuit in Fig. 1.2-30 uses the following:

- Push button **PB$_1$** (**NC**)
- Push button **PB$_2$** (**NO**)
- Control Relay **CR**
- Normally-Open relay contacts **CR**

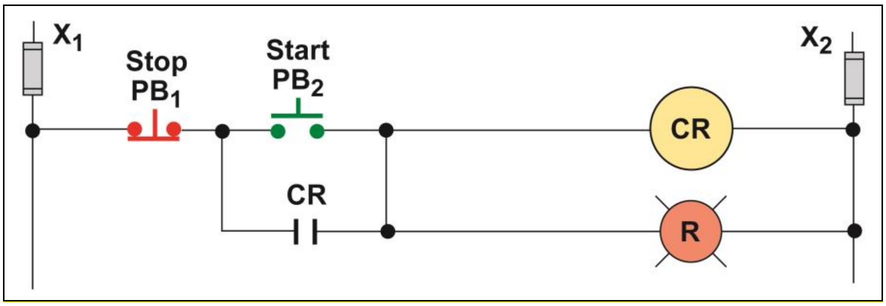


Fig. 1.2-30 Holding Circuit

GREEN INDICATING LAMP CIRCUIT OPERATION

After you have connected and operated a holding circuit, modify it by connecting a Green indicating lamp to a Normally-Closed contact on relay **CR$_1$**, as shown in Fig. 1.2-31.

Before PB2 is pressed

- **CR** is not energized and lamp R is off.
- Lamp G is lit by the circuit from **X_1** to **PB_1** and through **NC** contact **CR_2**.

When PB2 is pressed

- **CR** is energized.
- **NO CR_1** contact is closed.
- **NC CR_2** contact is open.
- Lamp **R** is lit.
- Lamp **G** is off.

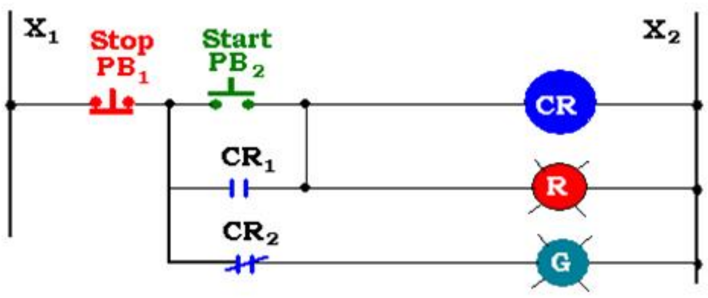


Fig. 1.2-31 Control Circuit with Red and Green Lamps

INTERLOCKING OPERATION

Many circuits require special safety devices to make sure that two parts of the circuit are not energized at the same time. The method used to do this is called Interlocks as safety devices for Forward/Reverse starters. Interlocks prevent the forward and reverse contactors from being energized at the same time. In this way interlocks prevent short circuits.

There are two types of interlocks used in control circuits, as shown in the following table:

Electrical		**Mechanical**
Push Button Electrical Interlocking	Contact Electrical Interlocking	Hinged Latch

MECHANICAL INTERLOCKS

When one contactor is energized, the mechanical interlock mechanism operates so that the other contactor cannot close its contacts. Fig. 1.2-32 shows a schematic diagram of a Forward/Reverse magnetic starter that is controlled by three Push-buttons with mechanical interlocking. The broken line that runs from the forward contactor coil to the reverse contactor coil indicates that the coils are mechanically interlocked. This mechanical interlock is installed at the factory by the manufacturer.

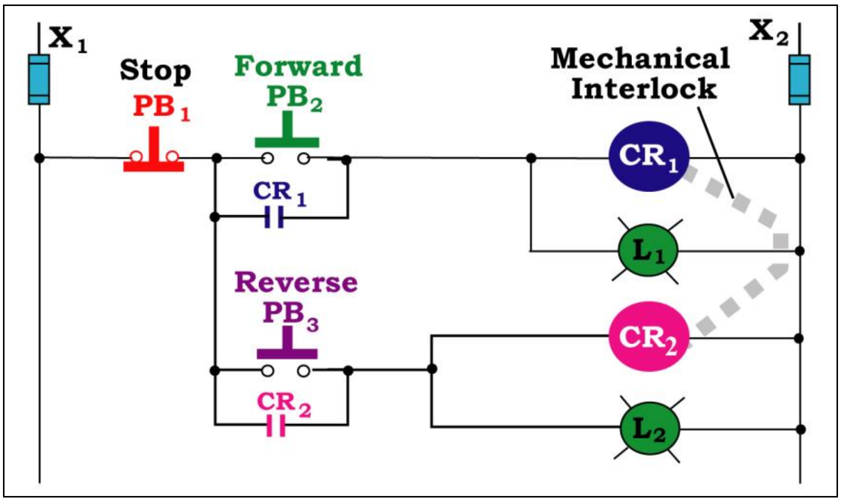


Fig. 1.2-32 Mechanical Interlock Circuit

OPERATION

- Depressing forward Push-button **PB$_2$** completes the forward coil circuit from **X$_1$** to **X$_2$**, energizing coil **CR$_1$**. Coil **CR$_1$** in turn will close auxiliary contacts **CR$_1$**. Mechanical interlocking keeps the reversing circuit from closing.
- Depressing stop button **PB$_l$** opens the forward coil circuit, causing coil **CR$_1$** to de-energize and contacts **CR$_1$** to return to their normally open position.
- Depressing reverse push button **PB$_3$** completes the reverse coil circuit from X_l to X_2, energizing coil **CR$_2$**. Coil **CR$_2$** in turn will close auxiliary contacts **CR$_2$**. Mechanical interlocking keeps the forward circuit from closing.
- Depressing stop button **PB$_l$** opens the reverse coil circuit, causing coil **CR$_2$** to de-energize and contacts **CR$_2$** to return to their normally open position.

ELECTRICAL INTERLOCKS

Most Forward/Reverse magnetic starters have mechanical interlock protection. Some Forward/Reverse starters have mechanical interlock protection with a secondary backup or safety backup system, to insure electrical interlocking. Fig. 1.2-33 Interlock Circuit shows a schematic for a Forward/Reverse circuit with Push-button and contact Electrical Interlocking. This method of interlocking uses two sets of push-button contacts to control each relay coil.

When the FORWARD button, **PB_2**, in Fig. 1.2-33 is pressed, control relay **CR_1** is energized and the normally open (**NO**) contact **CR_1** closes to hold in the forward relay **CR_1**. The indicating light, **L_1** will glow. If the REVERSE button, **PB_3** is pressed while the **CR_1** relay is energized, the forward control circuit is de-energized and the **CR_2** relay is energized and held closed. The indicating light, **L_2** will glow. If both **PB_2** and **PB_3** are pushed at the same time, neither relay can be energized.

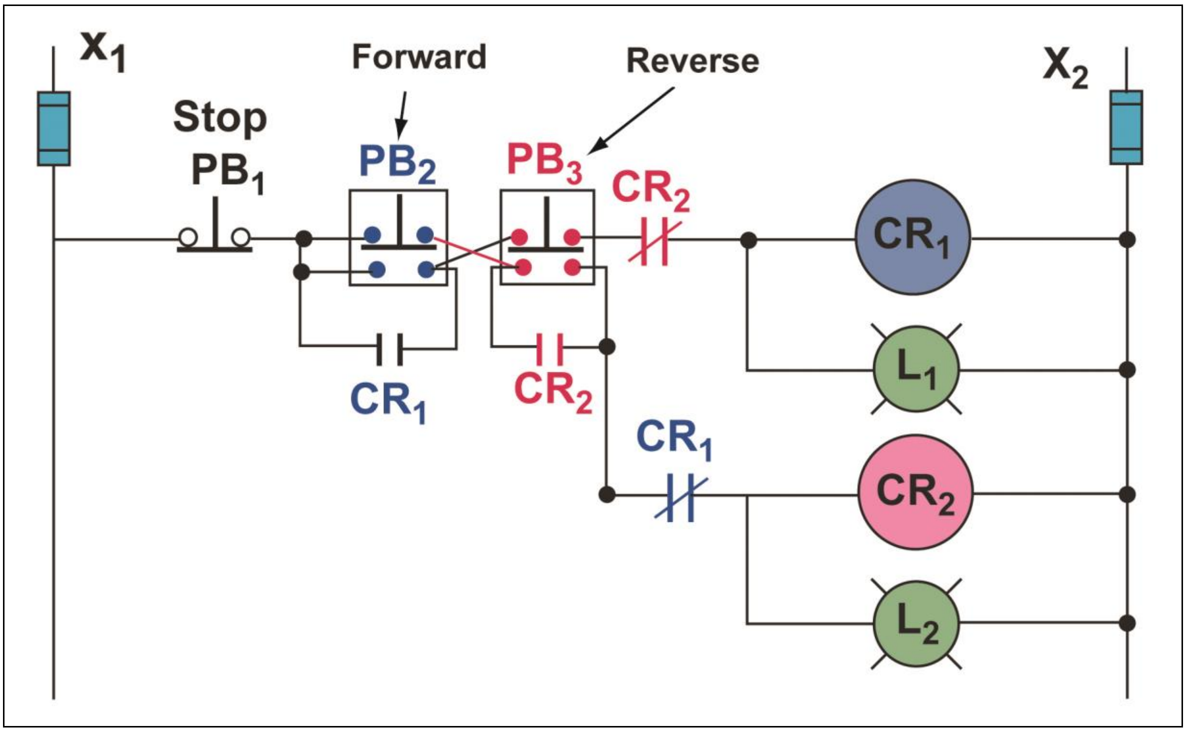


Fig. 1.2-33 Push-Button and Contact Electrical Interlock Circuit

STARTERS AND CONTACTORS

Magnetic contactors are used to control electrical power circuits when the overload protection is not required or when overload protection is separately provided.
Magnetic starters are used for full voltage, across the line starting and stopping induction motors. They can be operated locally or remotely. Magnetic contactors and starters are used in motor control circuits when there is a difference between the current carrying capacity of the controlling switches and the motor windings.

A magnetic contactor can use a small current through the controlling switch energizing an electromagnetic solenoid coil to control a high current load. This coil then opens or closes a switch in a line carrying high current from the supply to the motor. Fig. 1.2-34 shows a three-pole solenoid-operated magnetic contactor.

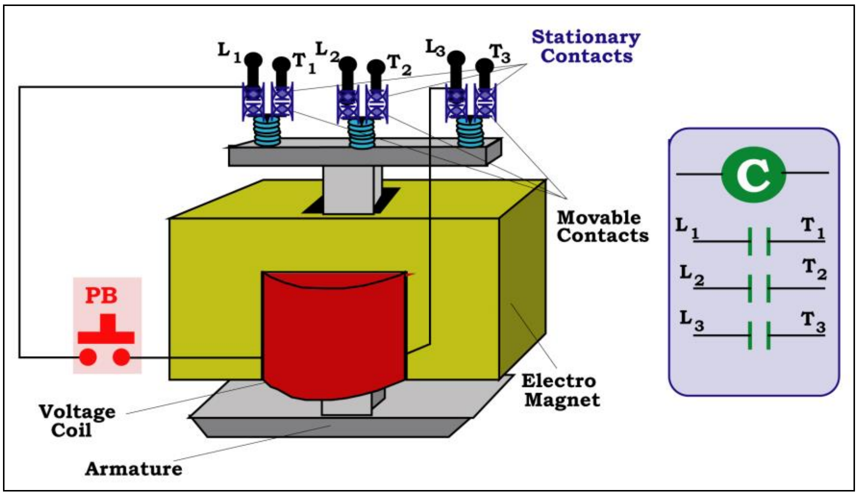


Fig. 1.2-34 Three-Pole, Solenoid-Operated Magnetic Contactor

MAGNETIC STARTERS

Magnetic starter includes a control coil for pick up and drop out functions. A magnetic motor starter is a combination of magnetic contactor and overload unit with power, auxiliary and overload contacts, as shown in Fig. 1.2-35. The starter core base is the bottom unit connected to the frame. Thermal overload heaters are directly attached to the starter core.

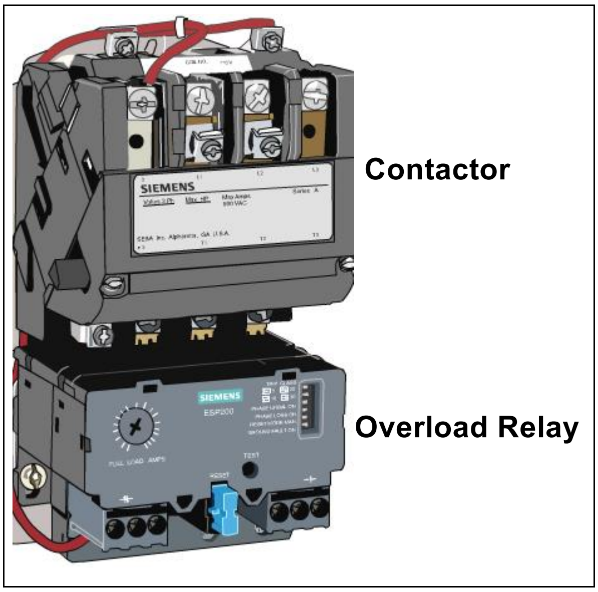


Fig. 1.2-35 Magnetic Starter with Overload Relay

OPERATION OF MAGNETIC STARTER

The magnetic starter operates on the same principle as the magnetic contactor with additional overload contacts. Fig. 1.2-36 shows a schematic diagram of a magnetic starter with **Auxiliary** and overload contacts. The auxiliary contact is added to form a holding circuit. This contact eliminates the need to keep holding the start button once the control circuit has been energized. The overload protection for magnetic starter is very similar to overload protection for manual starter. The main difference is that manual starter overload devices actually open the power contacts on the starter. The magnetic starter overload device opens a set of contacts only to the coil, as shown in Fig. 3.2-36. When the coil is de-energized, the power circuit is opened.

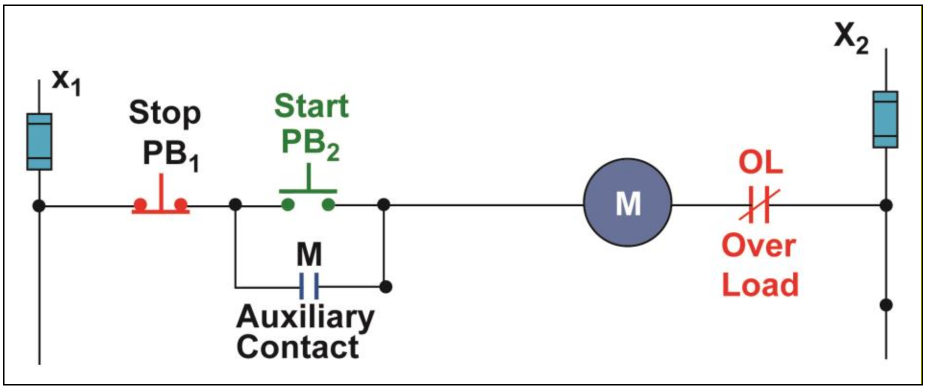


Fig. 1.2-36 Schematic Diagram of Magnetic Starter

Fig. 1.2-36, 37, 38, 39, 40 show the sequence of operation that occurs very quickly when the circuit is energized. Note that the auxiliary contacts are normally open and the overload contacts are normally closed. Fig. 1.2-36 shows the circuit before the START button is pushed. Depressing the **START** button allows current to pass from **X_1** through the magnetic starter coil **M** and through the Normally-Closed overload contacts **OL** to **X_2 (**Fig. 1.2-37).

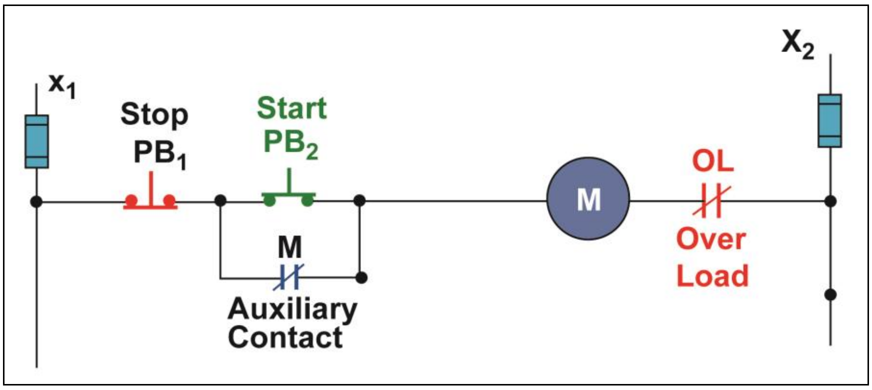


Fig. 1.2-37 Schematic Diagram of Magnetic Starter with Coil Energized

With the magnetic starter coil is energized, the auxiliary contacts **M** will close. The circuit will remain energized even if the START button is released (Fig. 1.2-38**)**.

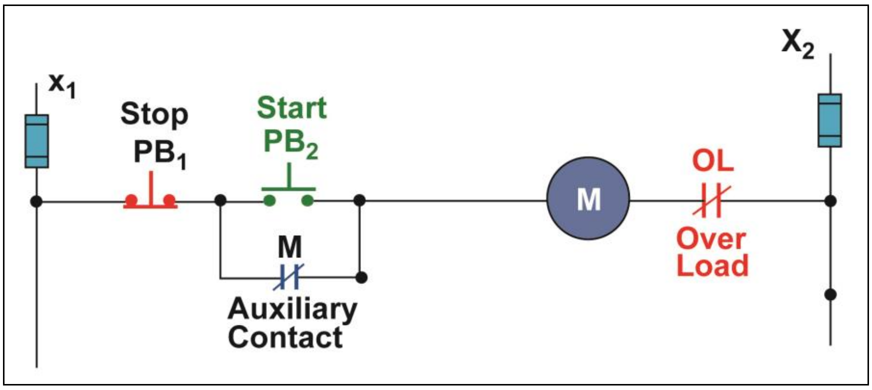


Fig. 1.2-38 Schematic Diagram of Magnetic Starter with Start Button Released

The circuit can be de-energized only if the **STOP** button is depressed, if an overload causes the Normally-Closed overload contact to open or if an interruption of the power supply occurs, (Fig. 1.2-39, 40).

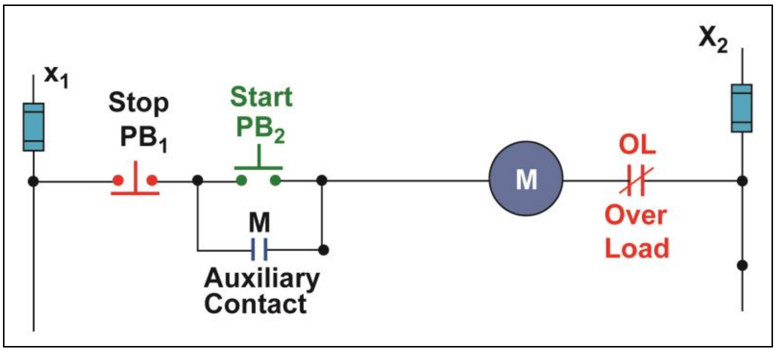


Fig. 1.2-39 Schematic of Magnetic Starter with Stop Button Depressed

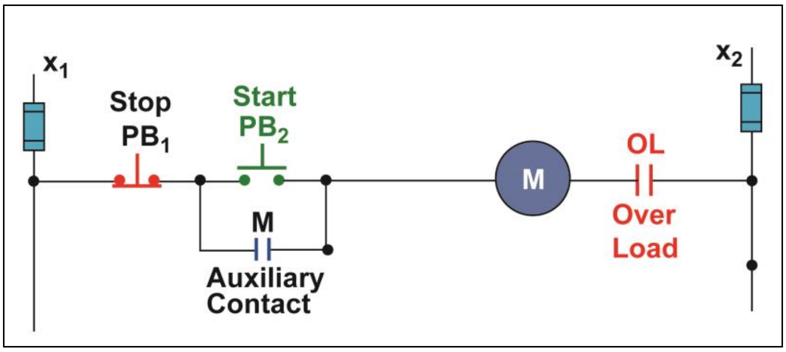


Fig. 1.2-40 Schematic of Magnetic Starter with Overload Contact Open

As shown in Fig. 1.2-39 & 40, when the magnetic starter coil **M** is de-energized, the auxiliary contact **M** returns to its Normally Open condition.

NOTE

When the motor stops because of an overload, the cause of the overload must be removed before attempting to restart the motor again. Then the overload contacts must be reset.

The **START** button must be pushed again in order to restart the motor.

WIRING DIAGRAM

Fig. 1.2-41 shows the control circuit drawing including the numbers of the terminal block points where the wires and devices are connected. This diagram shows the operation of the circuit but does not show the location or arrangement of the devices in the circuit.

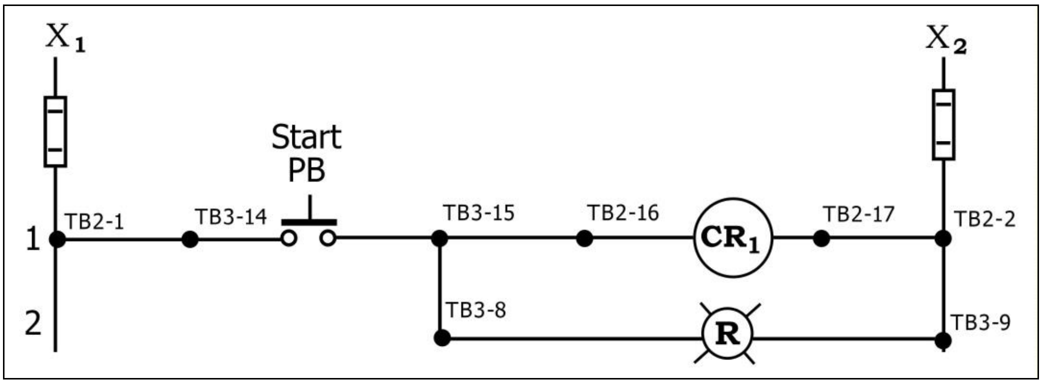


Fig. 1.2-41 Basic Control Circuit Diagram

The wiring diagram in Fig. 1.2-42(a, b) shows the layout or physical arrangement of the devices in the circuit and where each wire is connected.

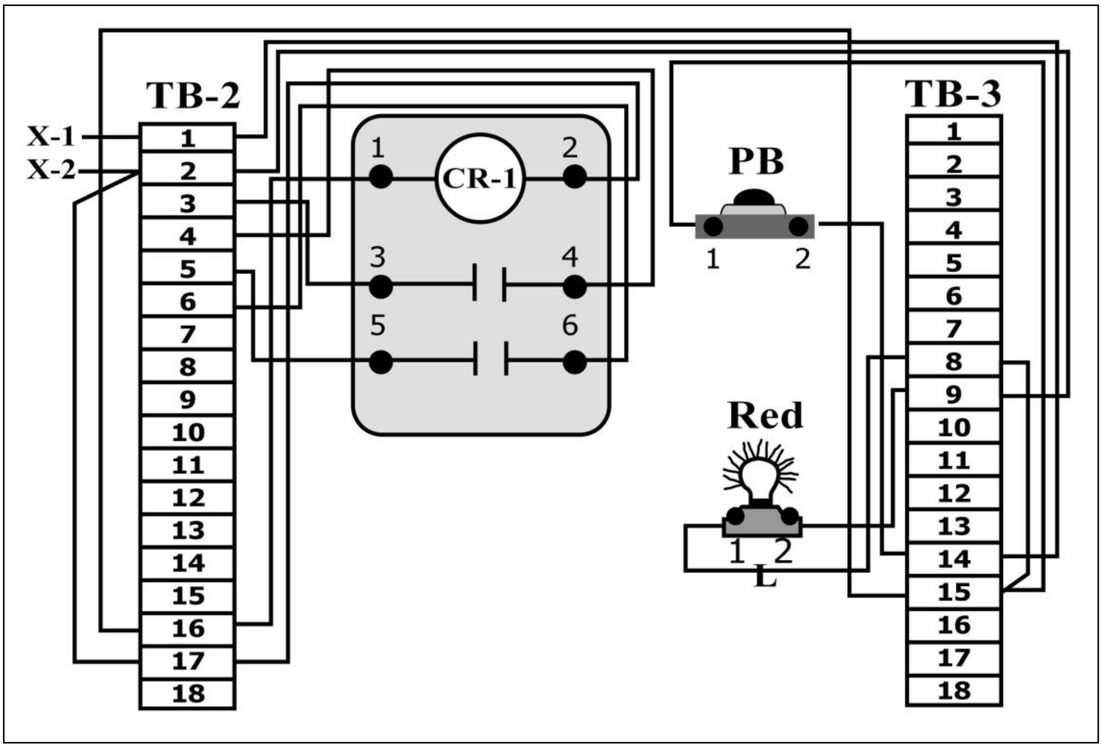


Fig. 1.2-42(a) Wiring Diagram

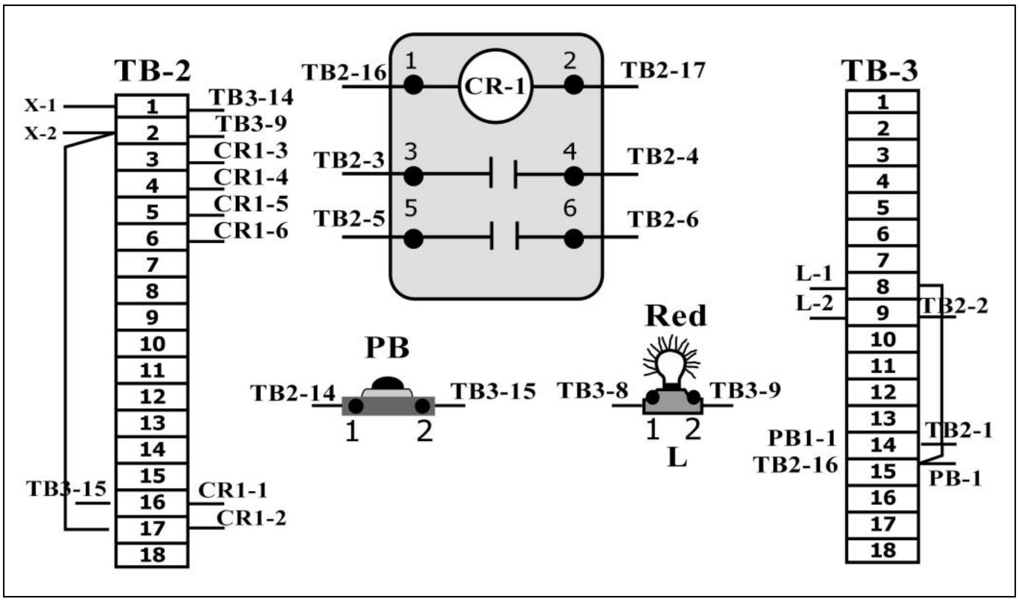


Fig. 1.2-42 (b) Wiring Diagram

CONTROL TRANSFORMER

Control transformer is used (for example) in motor control circuits to operate such circuits at low voltage for safety of personnel. Commonly adopted control voltage is 120V AC. Fig. 1.2-43 shows motor control circuit utilizing control transformer.

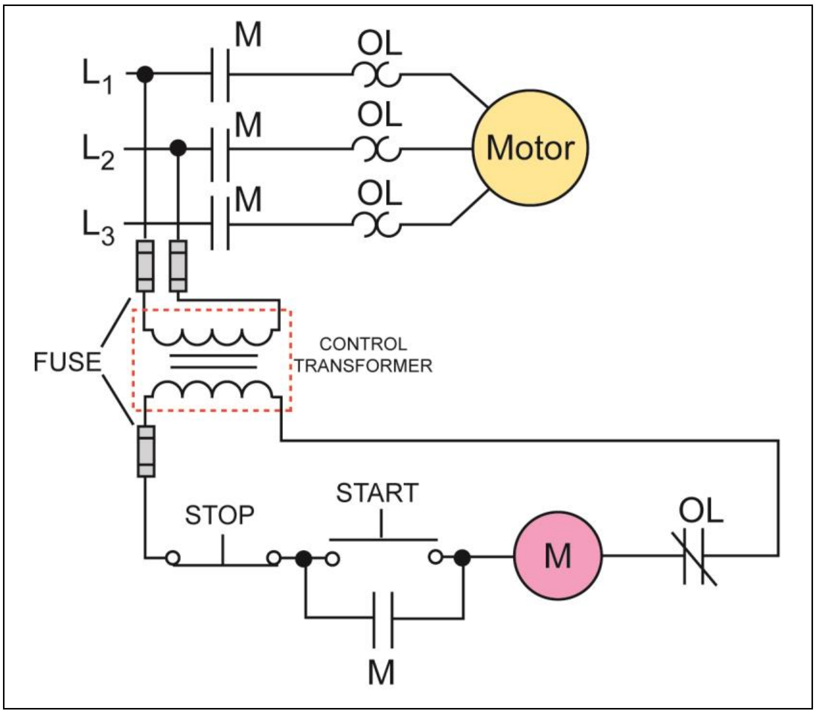


Fig. 1.2-43 Control Transformer Application

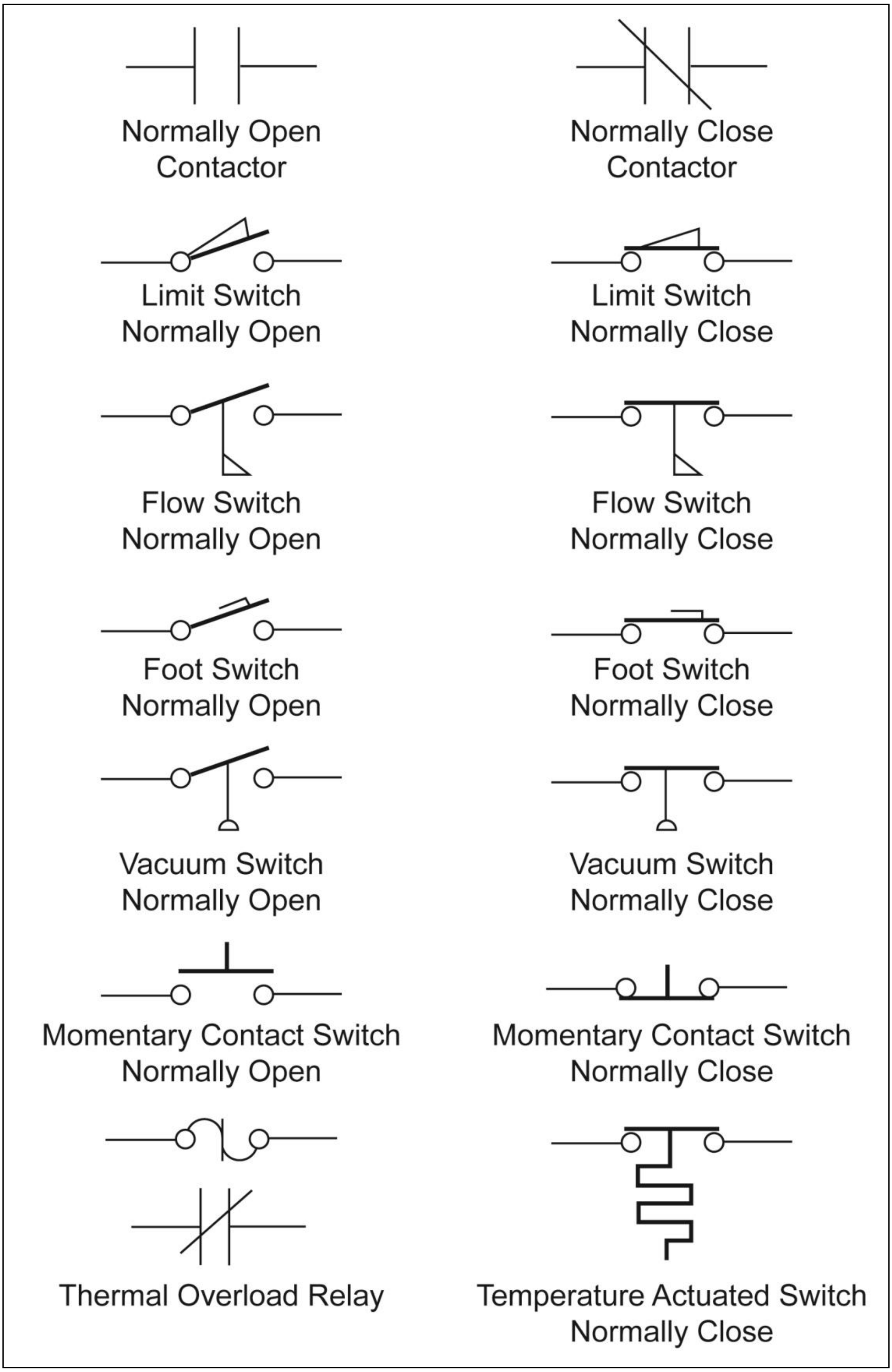


Fig. 1.2-44 Common Symbols for Motors Control

SUMMARY

- Control Devices are employed in motor control circuits to ensure that the stipulated pre-conditions are satisfied before the starting of motor.
- A push-button is a control device used to open and close, manually, a set of contacts.
- Selector switches are another means to open and close, manually, the contacts and are commonly used to select one of two or more circuit possibilities.
- Limit switches are one of the most widely used pilot devices in motor control circuits.
- A temperature switch opens or closes its contacts to control the heaters when its sensor detects a preset temperature.
- The relay uses solenoid operation to move a set of electrical contacts from the open to the closed position and vice versa.
- A timer relay has contacts to open or close with time delay after its coil is energized.
- Solid state timer relays provide high accuracy. It can be reset as quickly as 20 ms.
- Overload protection can be provided by a bimetal overload relay.
- Interlocks prevent the forward and reverse contactors from being energized at the same time. In this way interlocks prevent short circuits.
- Magnetic contactors are used to control electrical power circuits when the overload protection is not required or when overload protection is separately provided.
- A magnetic motor starter is a combination of magnetic contactor and overload unit with power, auxiliary and overload contacts.
- Control transformer is used (for example) in motor control circuits to operate such circuits at low voltage for safety of personnel.

GLOSSARY

SPST	Single Pole Single Throw
SPDT	Single Pole Double Throw
DPST	Double Pole Single Throw
DPDT	Double Pole Double Throw
NC	Normally-Closed contacts
Indicator Lamp	Warning light
Thermal Time Delay	opening or closing Delay with temperature effect

REVIEW EXERCISE

Fill in blanks

1. A single-pole-single-throw switch has (two / three) __________ switch positions
2. A NO momentary switch remains in the (open / close) ______________ position when released after pressing momentarily.
3. A START switch is a (momentary / maintained) _________________ switch.
4. A STOP switch has (NO / NC) _________________contacts.
5. A START Push-button switch has (NO / NC) _________________contacts.
6. A (NC / NO) ______ pressure switch is used to switch a compressor ON when the pressure drops below a certain value.
7. A (NC / NO) ______ pressure switch is used to switch OFF a compressor when the pressure rises to a certain value.
8. In a pump-motor circuit, a (NC / NO) _______ level switch is used to turn ON the motor when the level rises to a certain point.
9. In a pump-motor circuit, a (NC / NO) ________ level switch is used to turn the motor OFF when the level drops to a certain point.
10. What is the basic difference between an AC relay and DC relay?

    ____

    ____
11. List four types of operating mechanisms used in timer relays.

    (1) __________________________ (2) __________________________

    (3) __________________________ (4) __________________________
12. Name five control devices used in motor control circuits.

    (1) __________________________ (2) __________________________

    (3) __________________________ (4) __________________________

    (5) __________________________

TASK 1.2-1

CONTROL EQUIPMENT

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Identify different types of Control Equipment.

TOOLS, EQUIPMENT AND MATERIALS

- Motor driven timing relay
- Solid state timing relay
- Limit switch
- Pressure switch
- Temperature switch
- Flow switch
- Float switch

PROCEDURE

For each of the following control equipment:

- Identify the parts of the timer relays.
- Operate the timer relays, mechanically.
- Operate the timer relays, electrically.
- Identify the switch.
- Operate the switch, manually.
- Use a multimeter to measure each contact resistance in the two positions.

TASK 1.2-2

FULL VOLTAGE STARTER

OBJECTIVES

Upon completion of this task, the trainees will be able to:

- Wire and test Full Voltage Starter for Squirrel Cage Induction Motor.

EQUIPMENT AND TOOLS

- 1-ACC-100 Trainer
- 1-Miscellaneous Wires
- 1-3ϕ Induction Motor

PROCEDURE

1. Wire the circuit shown in Fig. 2-1.

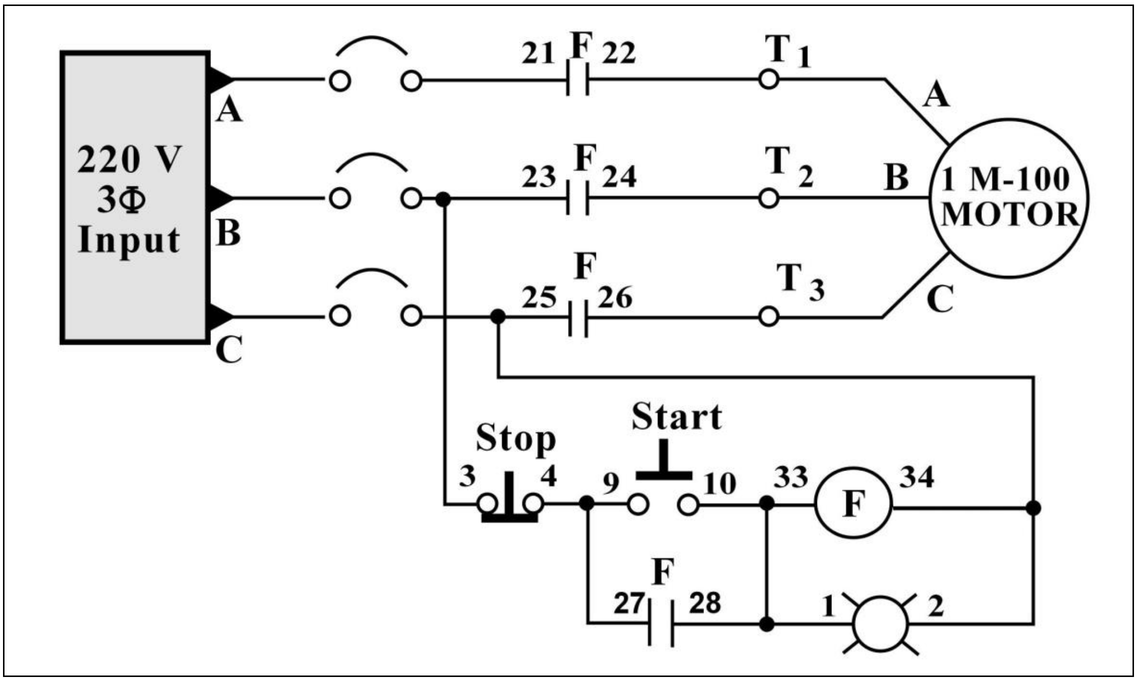


Fig. 2-1 Wiring Diagram for Full Voltage Starter without Overloads

2. Have the instructor to check your work.
3. Operate the circuit.
4. Explain the sequence of operation to your instructor.
5. Disassemble, clean work area and return all equipment and material to their proper storage area.
6. For the diagram shown in Fig. 2-2.
   a. Explain its difference from the previous diagram.
   b. Explain step-by-step operation.

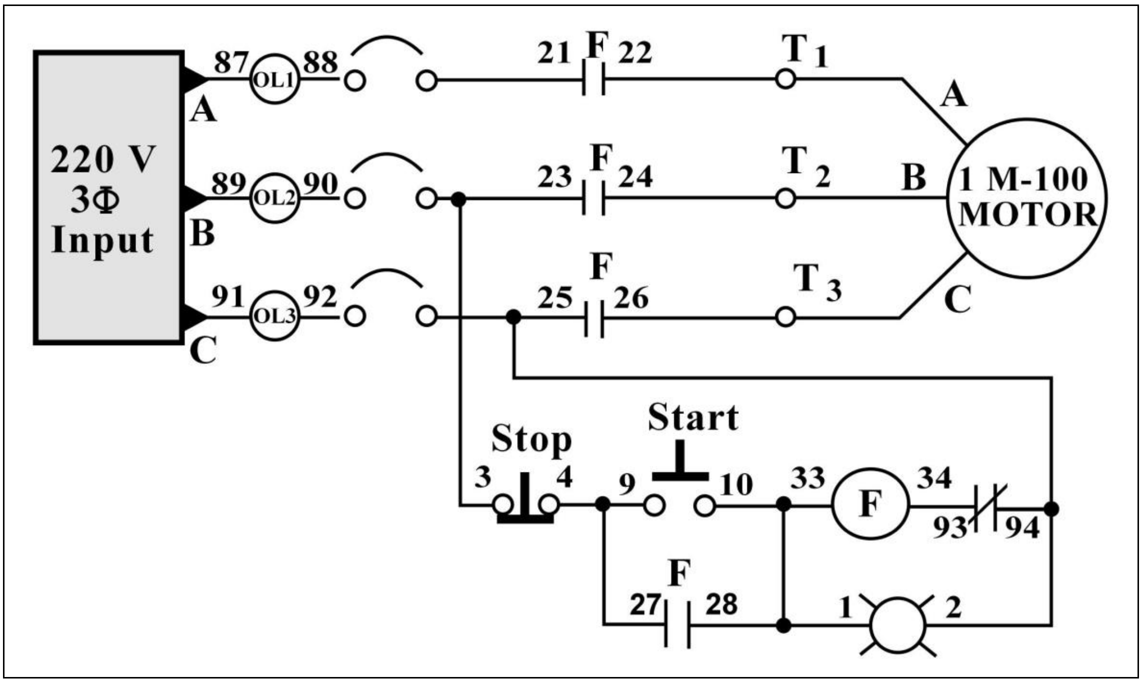
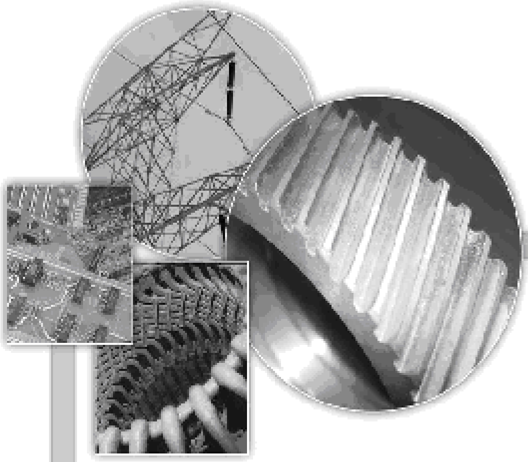


Fig. 2-2 Wiring Diagram for Full Voltage Starter with Overloads



UNIT 2

LESSON 2.1

TRANSFORMERS

LESSON 2.1
TRANSFORMERS

OVERVIEW

In this lesson, the principle of transformation of AC voltage from primary to secondary side is analyzed from the transformer characteristics deriving the relationships of Turns Ratio to voltage and current. The lesson concludes with the operation of auto-transformer.

OBJECTIVES

Upon completion of this lesson, the trainees should be able to:

- Explain the effect of mutual inductance in transformer characteristics.
- Explain the purpose and applications of the transformer.
- Explain transformer construction and operation of transformer.
- List the relationships of transformer ratio.
- Explain the operation of auto-transformer.

Task 2.1-1: Transformer Characteristics

Task 2.1-2: Transformer Polarity

INTRODUCTION

Transformers have many applications. They are used in electrical power systems to step up voltage for long distance transmission and then to step it down again to a safe level for use in our homes and offices. They are used in electronic equipment power supplies to raise or lower voltages, in audio systems to match speaker loads to amplifiers, in telephone, radio, and TV systems to couple signals, and so on.

WORKING PRINCIPLE OF A TRANSFORMER

The principle of the transformer operation is based on **electromagnetic mutual inductance**. The circuit shown in Fig. 2.1-1 illustrates a simple transformer.

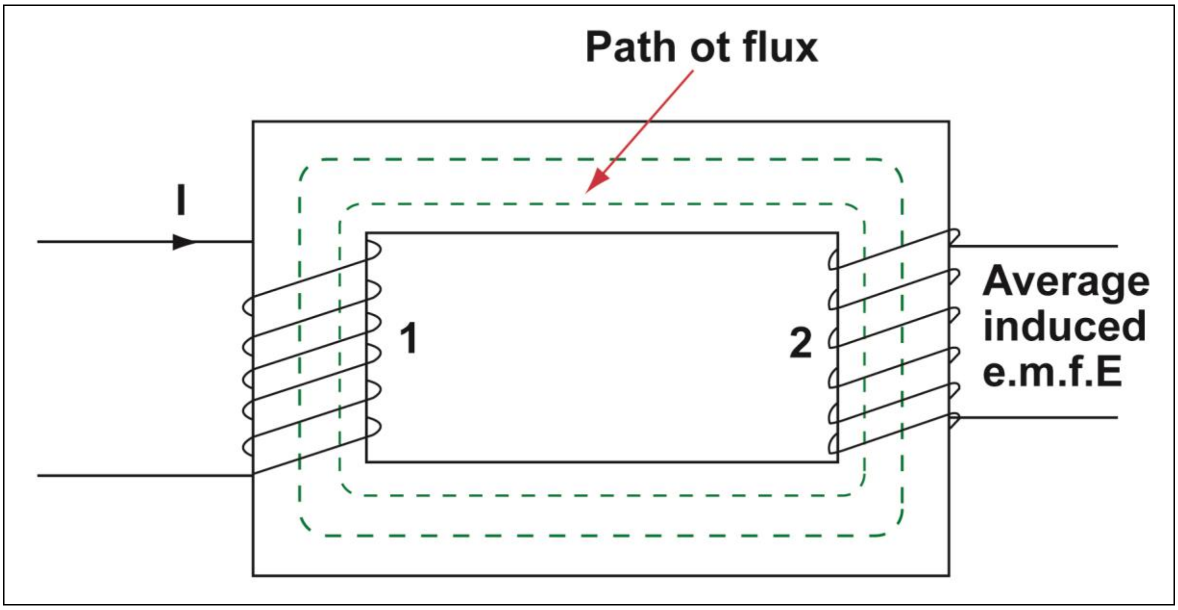


Fig. 2.1-1 Electromagnetic Mutual Inductance

A change of current in coil **1** produces a change of flux, which links with coil **2**, thus inducing an emf (electro-motive force) in that coil. These two coils are said to have the property of **mutual inductance**, which is defined as: A mutual inductance of 1H exists between two coils when a uniformly varying current of 1 A/s in one coil produces an emf of 1V in the other coil.

If a change of current ($I_1 - I_2$) in first coil induces an average emf **E** in the second coil, then:

$$\mathbf{E = -\frac{M\,(I_1 - I_2)}{t} \quad (Volt)}$$

Where : **E** = Inducd emf (volt)

M = Mutual inductance — t: Time (Sec)

I_1 = Current in coil **1** — I_2 = Current in coil **2**

The **coil 1** to which the AC voltage is applied is called the **primary winding**. Current in this winding (**I_1**) is caused by the AC voltage source and is called the **primary current**. The **coil 2** into which current is induced (**I_2**) is called the **secondary winding**. The induced current (**I_2**) is called the **secondary current**.

The amount of **emf** induced into the secondary winding depends on the amount of mutual induction between the two coils. The flux linkage can be thought of as the percentage of primary flux lines that cross the secondary winding. Another expression that means approximately the same thing is the **coefficient of coupling**. The coefficient of coupling is a number between **0** and **1**. When all the primary flux lines cut the secondary coil, ideally, the coefficient of coupling is **1**. If the two coils are positioned so that some of the primary flux lines do not cut the secondary, then the coefficient of coupling is **less than one**. If the two coils are positioned so that no primary flux lines cut the secondary, then the coefficient of coupling is **0**.

In brief, a transformer is a device that

- Transfers electric power from one circuit to another
- It does so without a change of frequency
- It performs this by electromagnetic induction and where the two electric circuits are in mutual inductive influence of each other.

The transformer is not used in DC circuits because it reacts to the rate of change of its applied voltage. The primary will create a magnetic field with DC but the secondary will not produce any emf if there is no change in magnetic field. Therefore there will be no secondary voltage delivered.

TRANSFORMER CONSTRUCTION

A transformer such as that shown in Fig. 2.1-2 consists of two coils called the primary and secondary coils or windings, wound on to a common core. The iron core of the transformer is not solid but made up of very thin sheets, called laminations, to improve efficiency.

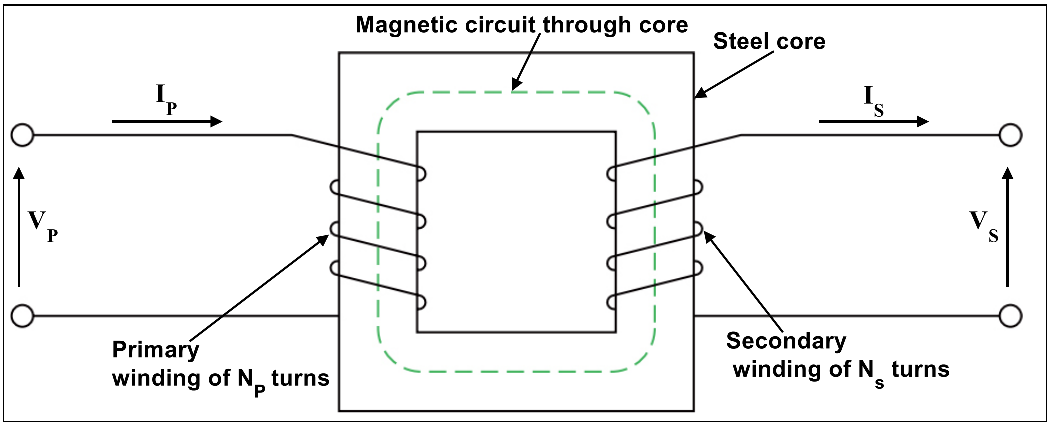


Fig. 2.1-2 Simple Transformer

The transformers are constructed in different shapes and sizes to accommodate electrical system requirements.

Large power transformers need cooling to take away the heat generated from the core. This is often achieved by totally immersing the core and windings in insulating oil. A sketch of an oil immersed transformer can be seen in Fig. 2.1-3.

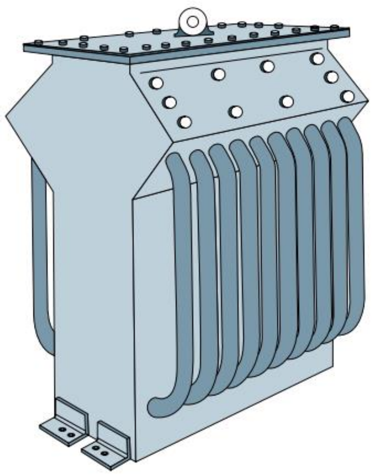


Fig. 2.1-3 Oil Power Transformer

TRANSFORMER RATIO

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient; all the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, the incoming electric power must equal the outgoing power (Fig. 2.1-4).

The input power = $V_P \times I_P \times PF$

The output power = $V_S \times I_S \times PF$

Giving the ideal transformer (Fig. 2.1-4) equation:

$$\mathbf{\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = K} \quad \textbf{(Turns ratio)}$$

Where: V_P = Primary voltage; V_s = Secondary voltage

I_P = Primary current; I_S = Secondary current

PF = Power Factor; K = Turns ratio

N_P = Number of turns in Primary Winding

N_s = Number of turns in Secondary Winding

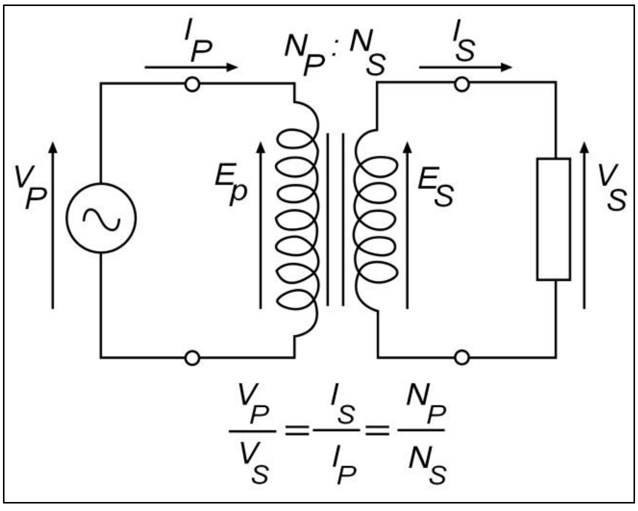


Fig. 2.1-4 Ideal Transformer

A transformer that **increases** voltage is called a **Step-Up** ($\mathbf{K < 1}$) transformer, as shown in Fig. 2.1-5(a). This type of transformer has more secondary turns than primary turns.

A transformer that **decreases** voltage is called a **Step-Down** ($\mathbf{K > 1}$) transformer, as shown in Fig. 2.1-5(b). Its primary winding has more turns than the secondary winding.

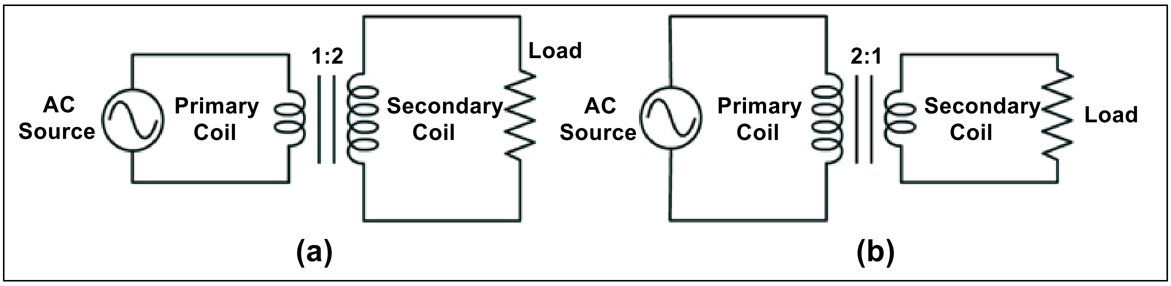


Fig. 2.1-5 Step-Up and Step-Down Transformer

EXAMPLE 4.1-1

A transformer has 27000 turns on the primary winding and 900 turns on the secondary. If a voltage of 230 V was applied to the primary side, calculate:

a. The transformer ratio

b. The secondary voltage

SOLUTION

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = K = \frac{27000}{900} = 30$$

a. As the secondary turns are fewer than the primary it must be a step-down transformer with a **ratio of 30:1.**

b. As the transformer is step-down with a ratio of 30:1, the secondary voltage will be 30 times less than the primary voltage.

$$V_S = \frac{V_P}{30} = \frac{230}{30} = 7.66 \text{ V}$$

TRANSFORMER EFFICIENCY

Efficiency is the ratio of output power to input power

$$\eta = \frac{P_{out}}{P_{input}} \times 100$$

$$P_{input} = P_{out} + P_{losses}$$

For a transformer, losses are due to $\mathbf{I^2R}$ losses in the windings (called copper losses) and losses in the core (called core losses).

Large power transformers are exceptionally efficient, of the order of 98 to 99 percent. The efficiencies of smaller transformers are around 95 percent or better.

AUTO-TRANSFORMER

An autotransformer is a special type of transformer with no isolation between the primary and the secondary windings but taps on the same primary winding. A single continuous coil is wound on a core. Part of this coil is used as the primary, while another part is used as the secondary. Usually, part of the coil is used as both primary and secondary.

Fig. 2.1-6 shows the auto-transformer being used to step down the applied voltage where the entire winding serves as the primary. The lower half of the coil is also used as the secondary winding. Because there are fewer turns in the secondary than in the primary, the voltage is stepped down and the current is stepped up.

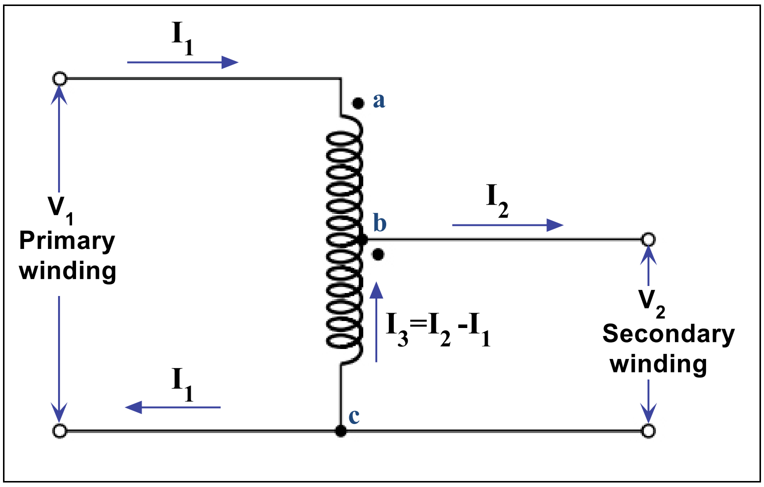


Fig. 2.1-6 Step Down Auto-Transformer

Autotransformers are compact, efficient and cost less. An auto transformer has only three terminal compared to four terminals for a normal transformer.

A normal transformer (Fig. 2.1-2) is sometimes referred to as a double wound transformer because of its two separate windings.

Its main **disadvantage** is that the secondary is not isolated from the primary. It is usually used in electronic circuits that have low current and high frequency requirements.

EXAMPLE 2.1-2

The primary and secondary voltages of an auto-transformer are 500 V and 400 V respectively. Show with the aid of diagram, the current distribution in the winding when the secondary current is 100 A

SOLUTION

I_2 (Secondary current) = 100 A

I_1 (Primary current) =?

V_1 (Primary voltage) = 500 V

V_2 (Secondary voltage) = 400 V

K (Turns ratio) = $V_2 / V_1 = 400 / 500 = 0.8$

I_1 (Primary current) = K $I_2 = 0.8 \times 100 = 80$ A

I_3 (Resultant current) = $(I_2 \;\; I_3) = 100 - 80 = 20$ A

The current distribution is shown in Fig. 2.1-7.

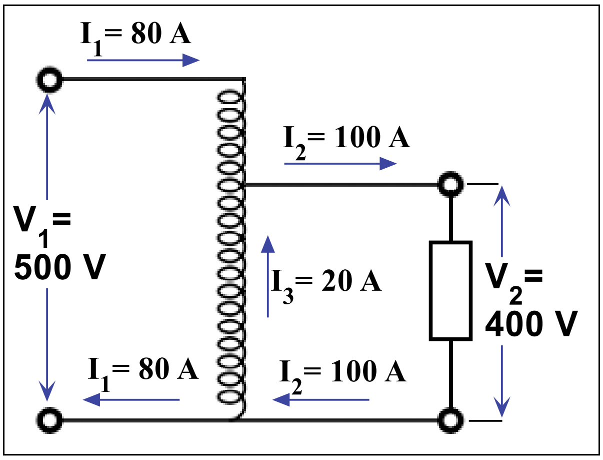


Fig. 2.1-7 Current Distribution

VARIABLE AUTOTRANSFORMER (VARIAC)

A variac is an autotransformer with a variable tap in a secondary side to change the turns ratio in which the output voltage in the secondary can be varied

Fig. 2.1-8 Single-phase tapped autotransformer with output voltage range of 40%–115% of input

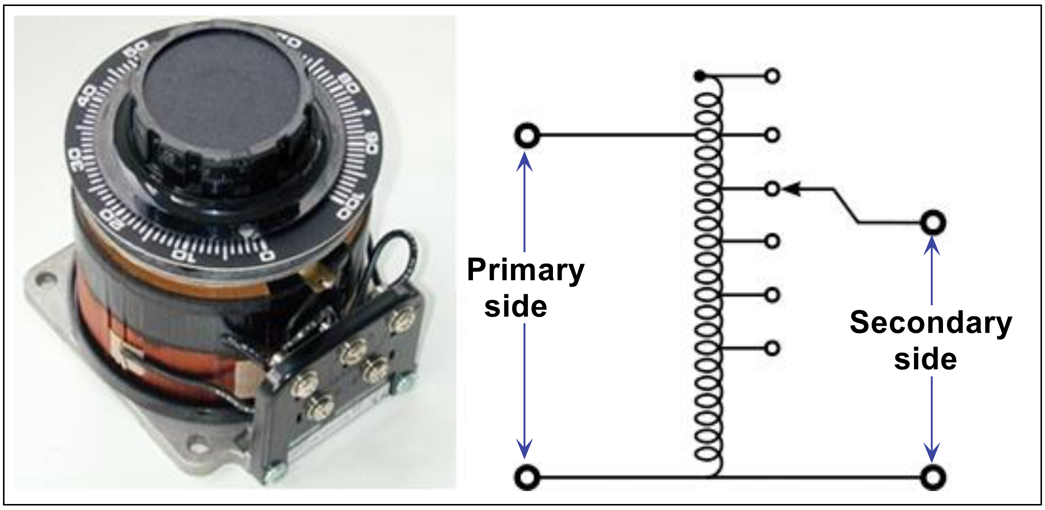


Fig. 2.1-8 Single-Phase Tapped Autotransformer (Variac)

TRANSFORMER POLARITY

A standard system of transformer polarity markings has been adopted by the electrical industry to simplify the installation of transformers in electrical systems. Transformers are manufactured with their primary and secondary winding terminals or leads labeled, H_1-H_2 and X_1-X_2, as shown in Fig. 2.1-9.

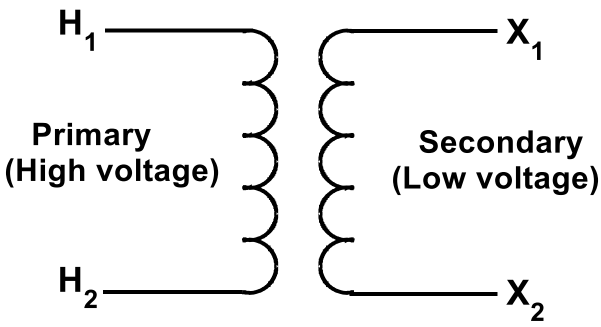


Fig. 2.1-9 Transformer Terminal Markings

The polarity of a transformer is simply an indication of direction of current flow from a terminal at any one instant. The idea is quite similar to the polarity marking on a battery. The polarity of a transformer can be either:

- Additive
- Subtractive

ADDITIVE POLARITY TRANSFORMER

When the high-side lead, $\mathbf{H_2}$, and low-side lead, $\mathbf{X_2}$, are brought out on the same side of the transformer and when the current flows in the opposite direction in the two adjacent primary and secondary terminals, the polarity is said to be **additive**, as shown in Fig. 2.1-10. If the leads $\mathbf{H_1}$ and $\mathbf{X_2}$ are connected and a given voltage is applied to the high side, the resultant voltage across the $\mathbf{H_2}$ and $\mathbf{X_1}$ leads is the sum of the high- and low-voltage windings.

NOTE

Additive polarity is more widespread in distribution-type transformers and subtractive polarity in power transformers.

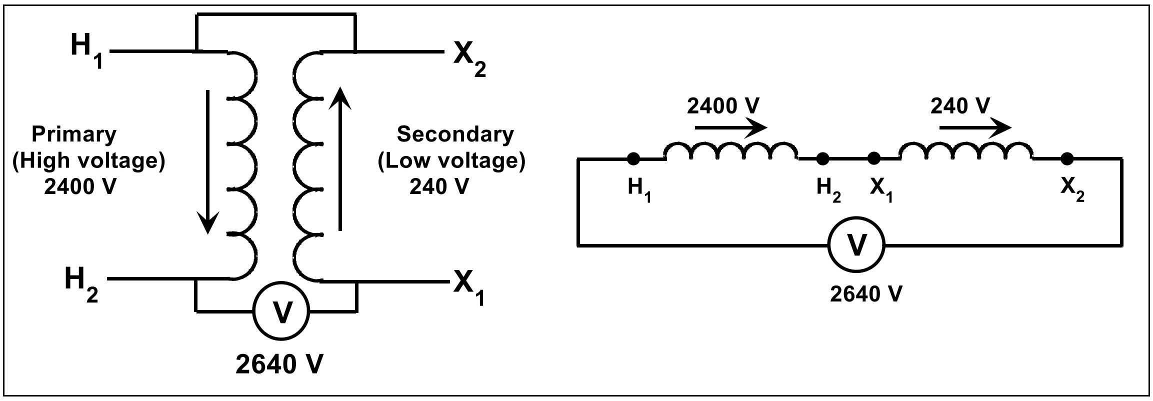


Fig. 2.1-10 Additive Polarity Transformer

SUBTRACTIVE POLARITY TRANSFORMER

When the high-side lead, $\mathbf{H_1}$ and low-side lead, $\mathbf{X_1}$, are brought out on the same side of the transformer and when the current flows in the same direction in the two adjacent primary and secondary terminals, the polarity is said to be **subtractive**, as shown in Fig. 2.1-11(a). If leads $\mathbf{H_1}$ and $\mathbf{X_1}$, are connected and the high side is energized with a given voltage, the resulting voltage, which appears across the $\mathbf{H_2}$ and $\mathbf{X_2}$ leads, will be less than the applied voltage, as shown in Fig. 2.1-11(b). This is due to the fact that in this series connection the low-voltage winding opposes the high-voltage winding, and thus the low voltage is subtracted from the high voltage.

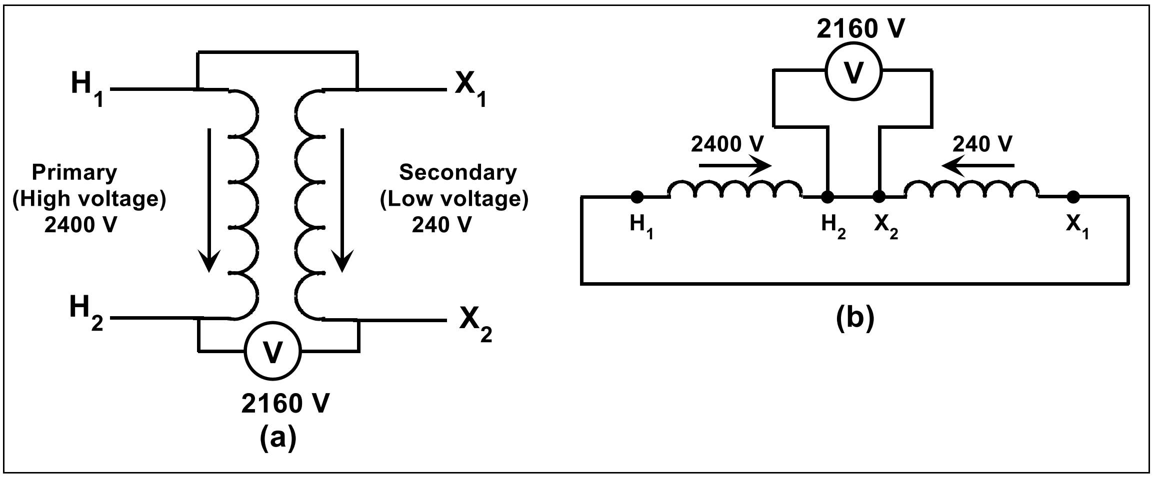
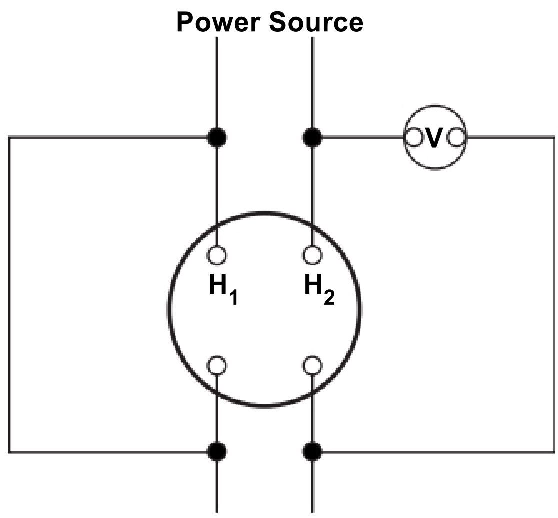


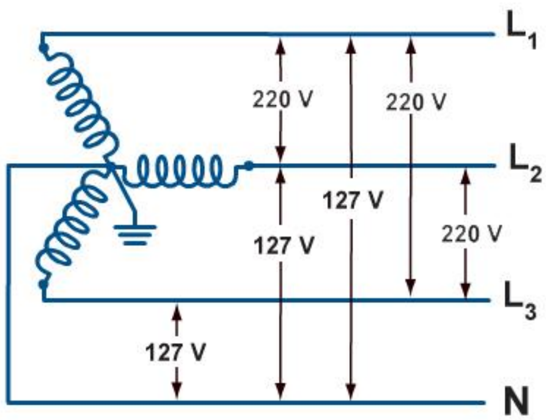
Fig. 2.1-11 Subtractive Polarity Transformer

POLARITY TRANSFORMER TEST

If a transformer is not marked, you can test it for polarity by connecting the transformer, as shown in Fig. 2.1-12. If it has subtractive polarity, V will be less than the voltage of the power source; if it has additive polarity, V will be greater than the voltage of the power source.	 Fig. 2.1-12 Polarity Test

TRANSFORMER APPLICATIONS

TRANSFORMERS IN POWER SYSTEMS

Transformers are used at **generating stations** to raise voltage for long-distance transmission. This lowers the transmitted current and hence the **I^2R** power losses in the transmission line. **At the user end**, transformers reduce the voltage to a safe level for everyday use. Fig. 2.1-13 shows the secondary of a wye-connected distribution transformer.	 Fig. 2.1-13 Secondary of Distribution Transformer

For example, suppose a generating station produces 12,000 volts at 10 Amperes. Let's assume that this 120,000 Watts of power is transmitted over a transmission line having a resistance of 100 Ohms. The power loss in the line is:

$P = I^2{}'R$

$P = (10\ A)^2 \times 100$ ohms

$P = 100 \times 100$

$P = 10{,}000$ Watts

Using a transformer, the 120,000 Watts can be transmitted as 120,000 V at 1 A. In this case, the power loss is:

$P = I^2R$

$P = (l\ A)^2 \times 100$ ohms = 100 Watts

Notice that by stepping the current down by a factor of 10, the power loss is reduced by a factor of 100. For this reason, power is transmitted (Fig. 2.1-14) over great distances at very high voltage levels and very low current levels.

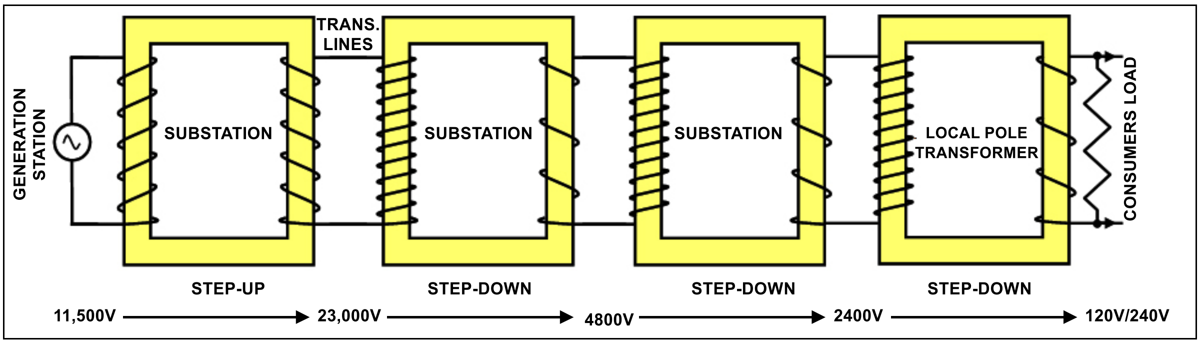


Fig. 2.1-14 Transformers Link the Generating Plant with Consumers

ELECTRONIC APPLICATIONS

POWER SUPPLY TRANSFORMERS

In electronic equipment, power supply transformers are used to convert the incoming 120 V AC to the voltage levels required for internal circuit operation.

A variety of commercial transformers are made for this purpose. The transformer of Fig. 2.1-15, for example, has a multi-tapped secondary winding, each tap providing a different output voltage. It is designed for laboratory supplies, test equipment, or experimental power supplies.

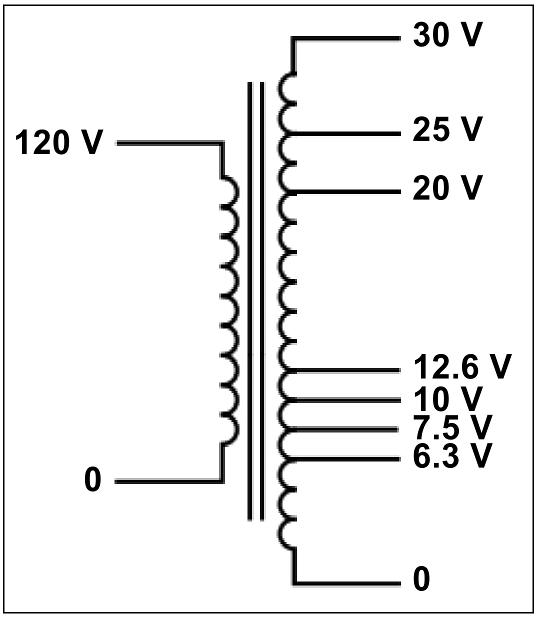


Fig. 2.1-15 Power Supply Transformer

Fig. 2.1-16 illustrates a typical use of a power supply transformer. First, the incoming line voltage is stepped down, then a rectifier circuit converts the AC to pulsating DC, a filter smoothes it, and finally, a voltage regulator regulates it to the required DC value. The rectifier circuit uses diodes to convert AC to DC using a process called rectification. The voltage regulator is an electronic device used to maintain a constant output voltage.

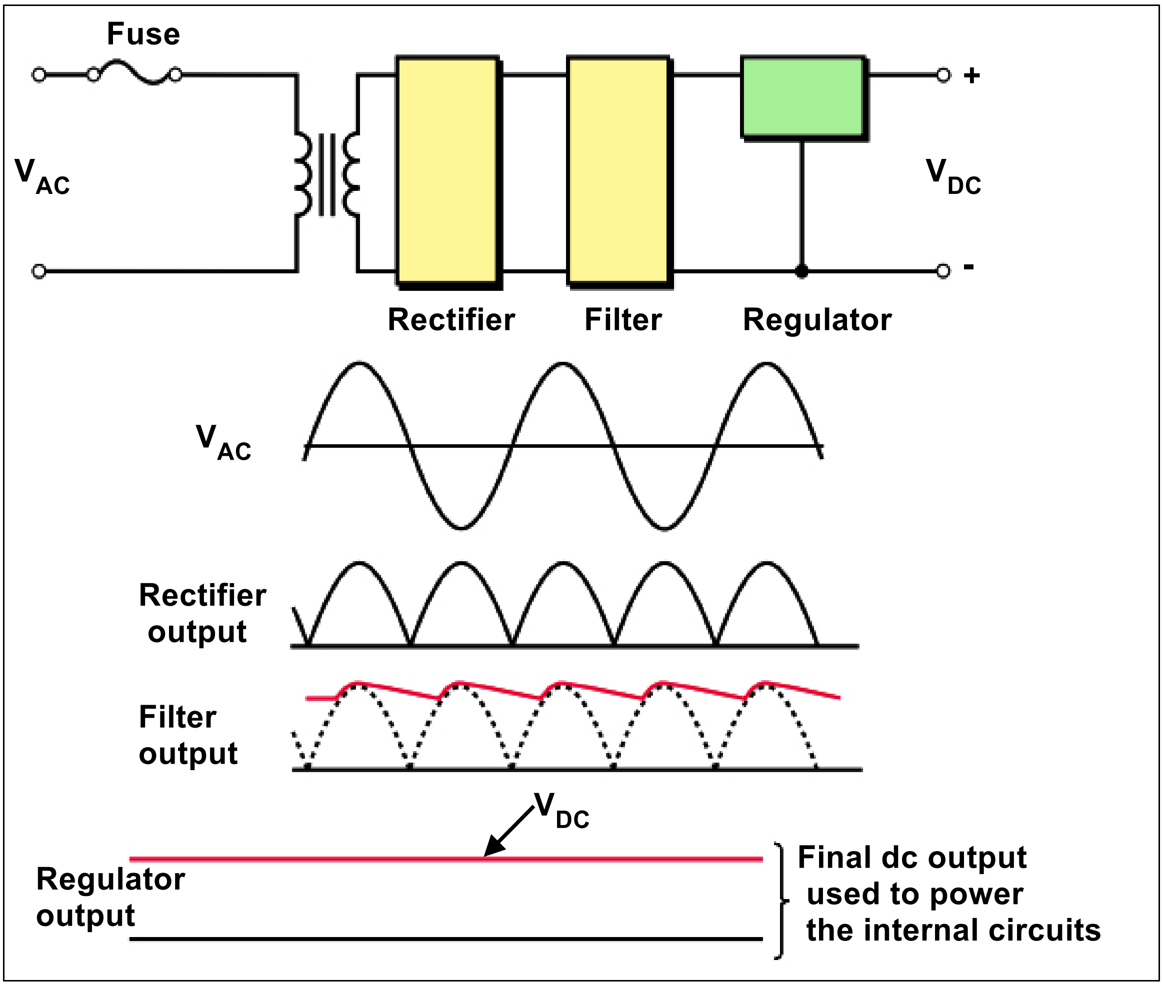
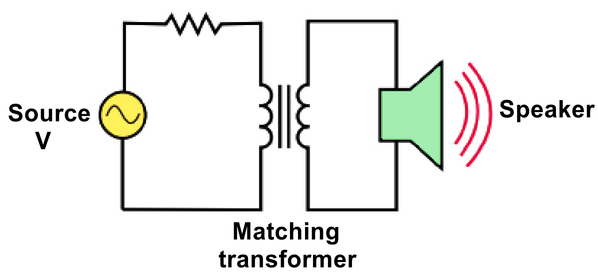


Fig. 2.1-16 Transformer Used In a Power Supply Application

IMPEDANCE MATCHING

In electronics one of the most important applications of a transformer is impedance matching. Maximum power is transferred from a source to a load when the impedance of the source matches the impedance of the load. If the load and source are not matched, a transformer can be inserted between them (Fig. 2.1-17).	 Fig. 2.1-17 Matching Transformer

ISOLATING TRANSFORMER

Transformers are sometimes used to isolate equipment for safety or other reasons. If a piece of equipment has its frame or chassis connected to "hot" wire (due to faulty installation for example) a dangerous situation results. A transformer used as in Fig. 2.1-18 eliminates this danger by ensuring that the chassis is never directly connected to the "hot" wire. **Isolation transformers** are made for this purpose.

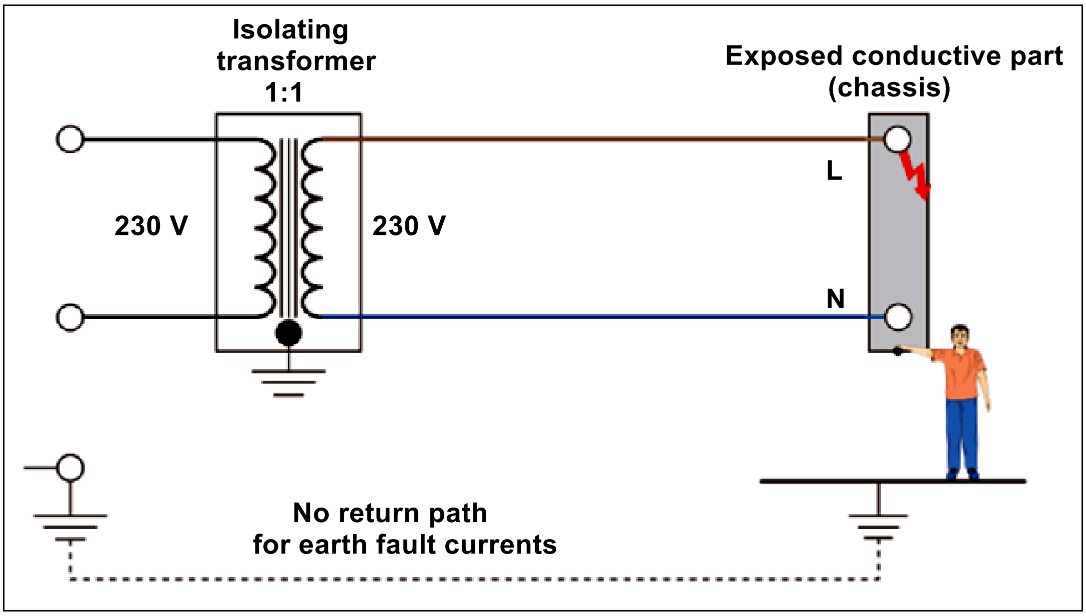


Fig. 2.1-18 Isolating Transformer

SUMMARY

- Transformers have many applications. They are used in electrical power systems to step up voltage for long distance transmission and then to step it down again to a safe level for use in our homes and offices.
- The principle of the transformer operation is based on electromagnetic mutual inductance.
- The transformer is not used in DC circuits because it reacts to the rate of change of its applied voltage.

- A transformer consists of two coils called the primary and secondary coils or windings, wound on to a common core.
- The iron core of the transformer is not solid but made up of very thin sheets called laminations, to improve efficiency.
- Electrical power is transmitted from the primary circuit to the secondary circuit.
- A transformer that increases voltage is called a Step-up transformer. This type of transformer has more secondary turns than primary turns.
- For a transformer, losses are due to I^2R losses in the windings (called copper losses) and losses in the core (called core losses).
- Large power transformers are exceptionally efficient, of the order of 98 to 99 percent. The efficiencies of smaller transformers are around 95 percent or better.
- An autotransformer is a special type of transformer with no isolation between the primary and the secondary windings but taps on the same primary winding.
- A standard system of transformer polarity markings has been adopted by the electrical industry to simplify the installation of transformers in electrical systems.
- The polarity of a transformer can be either: additive or subtractive
- Transformers are used at generating stations to raise voltage for long-distance transmission.
- The transformers are constructed in different shapes and sizes to accommodate electrical system requirements.
- Large power transformers need cooling to take away the heat generated from the core.
- On electronic equipment, power supply transformers are used to convert the incoming 120 V AC to the voltage levels required for internal circuit operation.

FORMULAS

$$\mathbf{E = -\frac{M\,(I_1 - I_2)}{t}\quad (Volt)}$$

Where: E = Induced emf (volt)

M = Mutual inductance   t: Time (Sec)

I_1 = Current in coil 1 I_2 = Current in coil 2

The input power = $V_P \times I_P \times PF$

The output power = $V_S \times I_S \times PF$

$$\mathbf{\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = K \quad (Turns\ ratio)}$$

Where: V_P = Primary voltage V_s = Secondary voltage

I_P = Primary current I_S = Secondary current

PF = Power Factor   K = Turns ratio

N_P = Number of turns in Primary Winding

N_s = Number of turns in Secondary Winding

Transformer efficiency:

$$\eta = \frac{P_{out}}{P_{input}} \text{ X } 100$$

Where: P_{out} = Output power of transformer P_{input} = Intput power of transformer

GLOSSARY

Mutual Inductance	A change of current in coil 1 produces a change of flux, which links with coil 2, thus inducing an emf (electro-motive force) in coil 2
Transformer	A device for changing the voltage of an alternating current by electromagnetic induction
Ideal Transformer	A transformer that the incoming electric power must equal the outgoing power without losses
Step-Up transformer	A transformer that **i**ncreases voltage. This type of transformer has more secondary turns than primary turns
Step-Down transformer	A transformer that decreases voltage. Its primary winding has more turns than the secondary winding
Efficiency	The ratio of output power to input power
An autotransformer	A special type of transformer with no isolation between the primary and the secondary windings but taps on the same primary winding
Polarity	A standard system of transformer has been adopted by the electrical industry to simplify the installation of transformers in electrical systems
Isolating Transformer	Transformers are sometimes used to isolate equipment for safety or other reasons
Matching transformer	Transformer can be inserted between the load and source to transfer Maximum power

REVIEW EXERCISE

1. The turns ratio of a transformer is 0.5. Is it a step-up or a step-down type? If the primary voltage is 100 V, what is the secondary voltage?
2. How many primary volts must be applied to a transformer with a turns ratio of 10 to obtain a secondary voltage of 60 V AC?
3. Determine the following quantities in Fig. 2.1-18:
   (a) primary current
   (b) secondary current
   (c) secondary voltage
   (d) power in the load

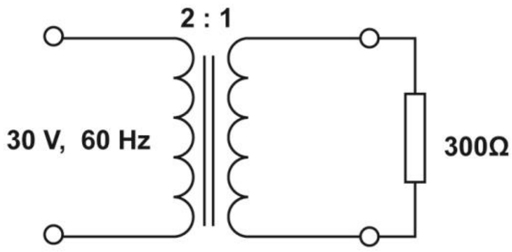


Fig. 2.1-18

4. Determine each unknown voltage indicated in Fig. 2.1-19.

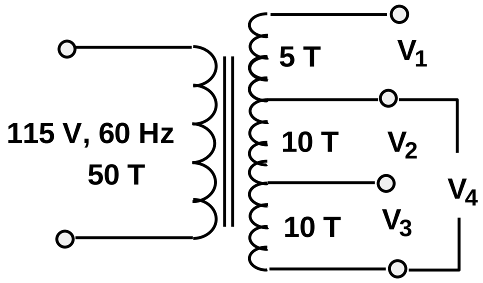


Fig. 2.1-19

5. Find the secondary voltage for each auto-transformer in the Fig. 2.1-20

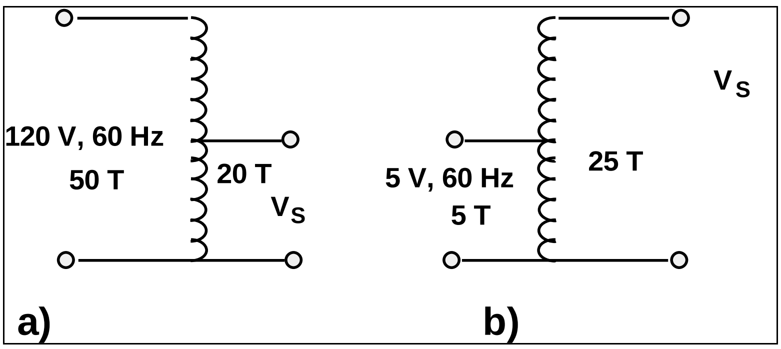


Fig. 2.1-20

TASK 2.1-1

TRANSFORMER CHARACTERISTICS

OBJECTIVES

Upon completion of this task, the trainees should be able to:

- Investigate the characteristics of a transformer.
- Measure some of the transformer parameters.

EQUIPMENT AND MATERIALS

- 1 - ET-3100 TRAINER
- 1 - VOM (multimeter)
- 1 - Audio Driver Transformer
- 1 - 1000 Ω, 1/2-watt resistor (brown, black, red)
- 1 - 100 Ω, 1/2-watt resistor (brown, black, brown)

PROCEDURE

1. Examine the construction of the audio transformer. Notice that it has a laminated core made up of **E** and **I** laminations. The primary and secondary are wound on a nylon bobbin around the center arm of the **E** lamination. The windings consist of several hundred turns of very fine copper wire. They are covered by a layer of tape for protection.
2. Fig. 1-1 shows a typical audio transformer. Identify the five leads on the transformer. Write the proper number of each pin on the protective tape immediately above the terminals.
3. Referring to Fig. 1-1(b), compare this schematic diagram of the transformer with the actual transformer.

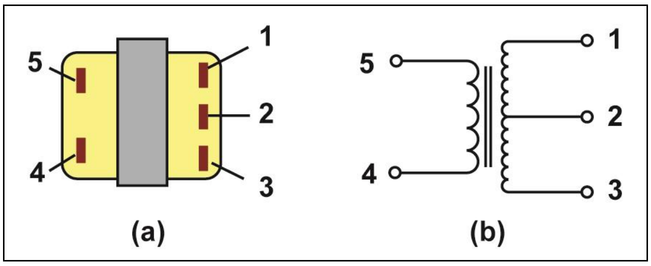


Fig. 1-1 Identification of Transformer leads

4. Referring to Fig. 1-2(a)**,** using an ohmmeter, measure the DC resistance of the winding between pins 4 and 5. We will call this resistance $R_{4\text{-}5}$.

   ($R_{4\text{-}5}$ = ________ Ohms)

5. Measure the resistance between pins 1 and 2, as shown in Fig. 1-2(c). We will call this resistance $R_{1\text{-}2}$. **($R_{1\text{-}2}$ = ________ Ohms)**

6. Measure the resistance between pins 2 and 3, as shown in Fig. 1-2(d).

7. Measure the resistance between pins 2 and 3, as shown in Fig. 1-2(d).

   (**$R_{2\text{-}3}$ = ________ Ohms**)

   ***Does $R_{2\text{-}3}$ equal $R_{1\text{-}2}$?* (________________)**

   What assumption can we make about the position of the tap that connects to pin?

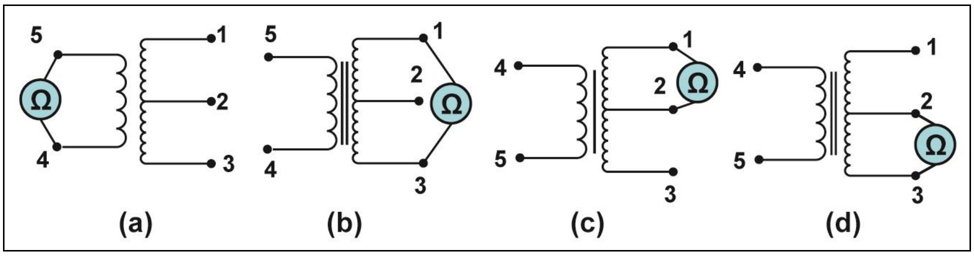


Fig. 1-2 Measure DC Resistance of Each Winding

8. Cut five 3-inch lengths of hook-up wire. Strip 1/4 inch of insulation from each end of each wire. Solder one wire to each of the five pins on the transformer.

9. Connect pins 4 and 5 of the transformer across the 15 VAC source terminals as shown in Fig. 1-3(a). Leave pins 1, 2 and 3 open.

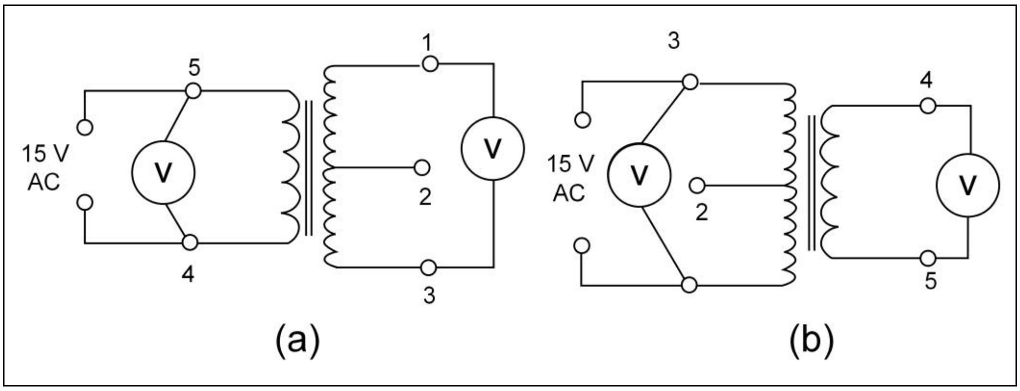


Fig. 1-3 Step-up and Step-down Transformers

10. Place your voltmeter on an AC voltage range and measure the voltage applied between pins 4 and 5. (**E_{4-5} =________ VAC).**

    Is the winding between pins 4 and 5 being used as a primary or as the secondary? (________________)

11. Measure the voltage between pins 1 and 3. **(E_{1-3} =________ VAC)**.

12. Compare the primary voltage with the secondary voltage.

    Is the applied voltage being stepped up or stepped down? (______________)

13. Determine the primary-to-secondary turns ratio of the transformer.

    Turns ratio = ________

14. Disconnect the transformer. Connect pins 1 and 3 across the 15 VAC source terminals, as shown in Fig. 1-3(b). Leave pins 2, 4 and 5 open.

15. Measure the applied voltage. **(E_{1-3} = ________ VAC)**.

    In this case, the winding between pins 1 and 3 is (primary/secondary)

16. Measure the voltage between pins 4 and 5. **(E_{4-5} = ________ VAC)**.

    The winding between pins 4 and 5 is the (primary/secondary) ____________

17. Compare the primary voltage with the secondary voltage.

    ***Is the applied voltage being stepped up or stepped down?* ___________**

18. Determine the secondary-to-primary turns ratio of the transformer.

    Turns ratio = ________

19. Does this turns ratio agree with that computed earlier in **Step 13**? ___________

    Which winding has more turns, the one between pins 4 and 5 or between pins 1 and 3? ___________

20. Connect pins 1 and 2 across the 15 VAC source terminals, as shown in Fig. 1-4(a). Leave pins 3, 4 and 5 open.

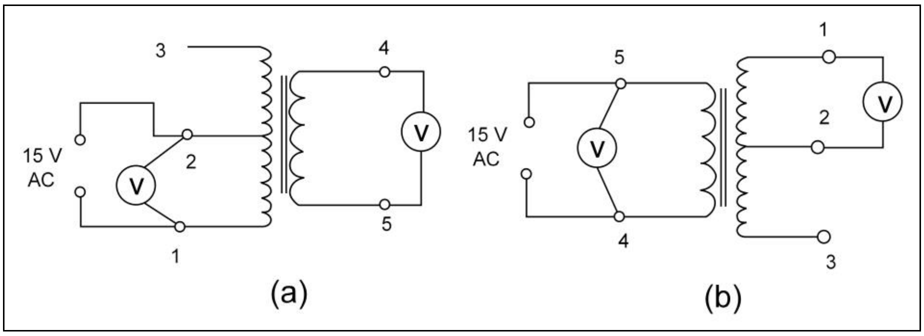


Fig. 1-4 Split Turns Ratio

21. Measure the voltage between pins 1 and 2. **($E_{1\text{-}2}$ = ________ VAC)**
22. Measure the voltage between pins 4 and 5. **($E_{4\text{-}5}$ = ________ VAC)**

    Did the voltage step up or step down? ________
23. Compute the turns ratio of the winding between pins 4 and 5 and the winding between pins 1 and 2. **(Turns ratio = ________)**
24. Disconnect the transformer. Connect pins 4 and 5, as shown in Fig. 1-4(b). Leave pins 1, 2 and 3 open.
25. Measure the voltage between pins 1 and 2. **($E_{1\text{-}2}$ = ________ VAC)**

    Did the applied voltage step up or down? ________
26. Compute the turns ratio of the winding between pins 4 and 5 and the winding between pins 1 and 2. **(Turns ratio = ________)**
27. Using the transformer and a 1k Ohm resistor, connect the circuit shown in Fig. 1-5(a). Leave pins 1, 2, and 3 open.

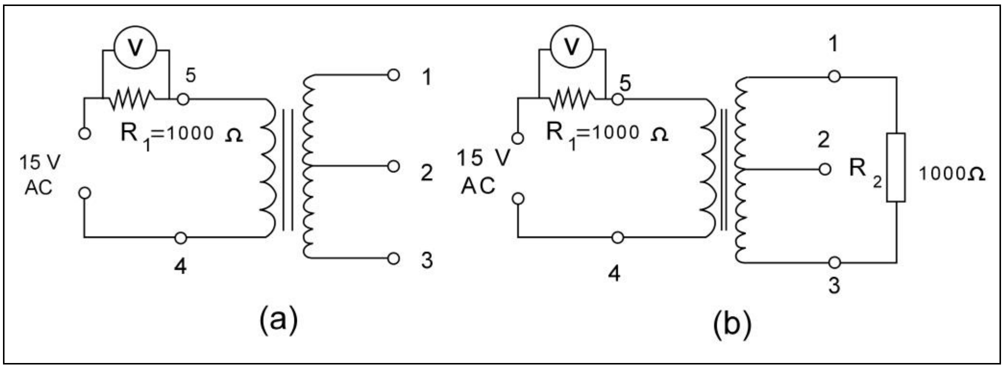


Fig. 1-5 Secondary Load Increasing Primary Current

28. Measure the voltage across **R_1**. **(E_{R1} = ________ V)**

    Calculate current in the primary by using Ohm's law. (Ip = ________ mA)

    Because the secondary has no load, this current is called the _______ current.

29. Load the secondary by connecting a 100 Ohm resistor (**R_2**) between pins 1 and 3.

    Now what is the voltage drop across R_1? (V_{R1} = ________ V)

    Find the current in the primary by using Ohm's law. (Ip = ________)

    When the secondary is loaded, primary current (increases/decreases) _______

30. Measure the voltage between pins 4 and 5 of the transformer. **($E_{4\text{-}5}$ = _____ V)**

31. Measure the voltage between pins 1 and 3 of the transformer. **($E_{1\text{-}3}$ ______ V)**

32. Using the values measured in **Steps 30** and **31**, determine the turns ratio.

    (Turns ratio = ________)

    Does this agree with the value computed in Step 13? (________)

    Does the turns ratio formula work when the transformer is loaded? (_______)

33. Using Ohm's law, determine the current in the secondary. **(Is = ________)**

    Does the voltage step up or down? (________)

    Does the current step up or down? (________)

34. Connect pins 1 and 2 of the transformer across the 15 VAC source terminals, as shown in Fig. 1-6(a). Leave pins 3, 4, and 5 open. If we ignore the winding between pins 4 and 5, the remaining winding can be thought of as an autotransformer.

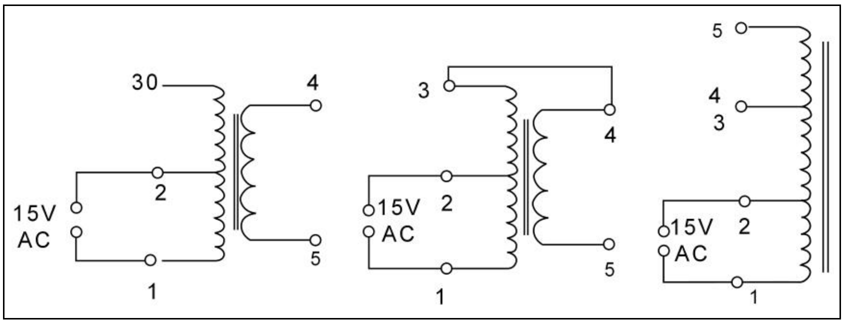


Fig. 1-6 Auto-Transformer

35. The voltage is applied between pins 1 and 2. Thus, the winding between pins 1 and 2 is the: **(________ winding)**
36. The output voltage is taken between pins 1 and 3. Thus, the winding between pins 1 and 3 is the: **(________ winding)**

    Which has more turns, the secondary winding or the primary winding? ______
37. The unused winding between pins 4 and 5 can be included in the makeshift auto-transformer. Connect pins 3 and 4 of the transformer, as shown in Fig. 1-6(b).
38. Measure and record the following values:

    $E_{1\text{-}2}$ = ________ VAC.

    $E_{1\text{-}3}$ = ________ VAC.

    $E_{1\text{-}4}$ = ________ VAC

    $E_{1\text{-}5}$ = ________ VAC

TASK 2.1-2

TRANSFORMER POLARITY

OBJECTIVES

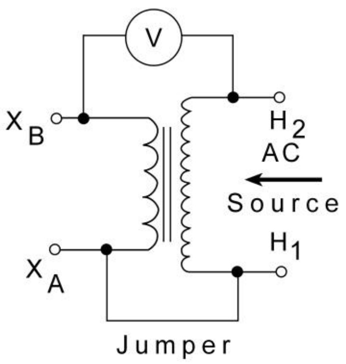
Upon completion of this task, the trainees should be able to:

- Determine the polarity of a given transformer.

EQUIPMENT AND MATERIALS

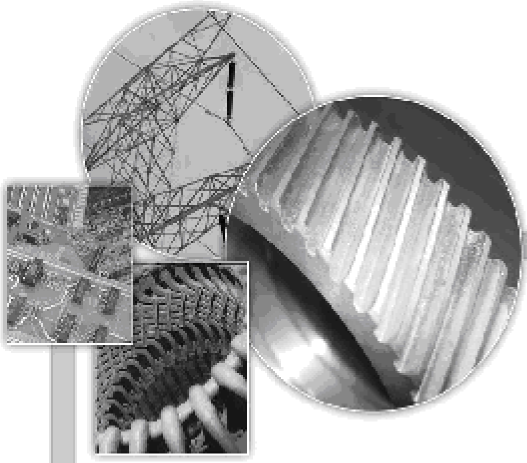
- 1 - Single phase transformer
- 1 – Voltmeter
- 1 - AC power supply 12OV
- Jumper leads

PROCEDURE

1. Look at the transformer from the high voltage side (marked with large arrow in the Fig. 2-1).	 Fig. 2-1

2. Mark the right hand terminal $\mathbf{H_1}$ and the left hand terminal $\mathbf{H_2}$.
3. Temporarily mark the low voltage terminals $\mathbf{X_A}$ and $\mathbf{X_B}$ as shown in Fig. 2-1.
4. Connect terminals $\mathbf{H_1}$ and $\mathbf{X_A}$ using the jumper wire.

5. Connect the AC voltmeter across terminals $\mathbf{H_2}$ and $\mathbf{X_B}$.
6. Connect $\mathbf{H_1}$ and $\mathbf{H_2}$ to the 120V AC supply. **Do Not Switch ON**.
7. Ask the Instructor to check your work.
8. Switch **ON** the AC supply.
9. If the voltmeter reading is less than the applied voltage, the polarity is **SUBTRACTTVE**.
10. Mark terminal $\mathbf{X_A}$ as $\mathbf{X_1}$ and terminal $\mathbf{X_B}$ as $\mathbf{X_2}$.
11. If the voltmeter reading is more than the applied voltage, the polarity is **ADDITIVE.**
12. Mark terminal $\mathbf{X_A}$ as $\mathbf{X_2}$ and terminal $\mathbf{X_B}$ as $\mathbf{X_1}$.



UNIT 3

SEMICONDUCTOR FUNDAMENTALS

UNIT 3
SEMICONDUCTOR FUNDAMENTALS

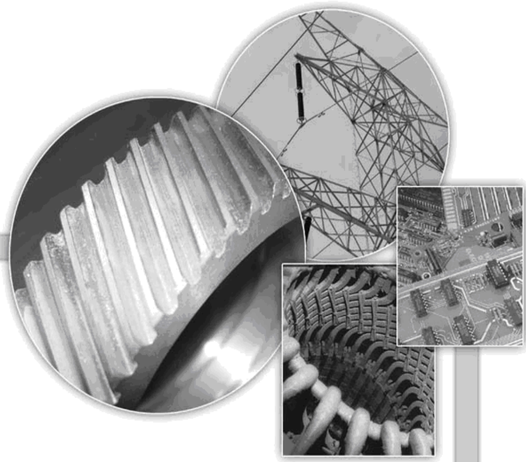
OVERVIEW

In this unit for the semiconductor applications, the trainees learn the importance of semiconductors to understand the behavior of electronic components, such as diodes and transistors utilized in most recent protective equipment.

OBJECTIVES

Upon completion of this unit, the trainees will be able to:

- Identify the semiconductor diodes and their applications.
- Demonstrate the bipolar junction transistor, characteristics and tests.
- Illustrate the transistor as an amplifier.
- Demonstrate the transistor circuit configurations and their applications.
- Verify wave-shaping circuits and their applications.
- Illustrate the oscillator circuits and their applications.



LESSON 3.1

SEMICONDUCTOR DIODES

LESSON 3.1
SEMICONDUCTOR DIODES

OVERVIEW

This lesson deals with semiconductor PN junction diodes, rectifiers and their applications in electric power systems.

OBJECTIVES

Upon completion of this lesson, the trainees will be able to:

- Identify the behavior of semiconductor bonding atoms.
- Demonstrate the diode characteristic and application.
- Illustrate the use of diode in half-wave rectifier circuits.
- Verifying the zener diode in the regulator applications.

Task 3.1-1: Demonstrating the Test of Semiconductor Diodes
Task 3.1-2: Demonstrating Half Wave & Full Wave Rectifiers
Task 3.1-3: Demonstrating the Zener Diode Operation, As a Voltage Regulator

INTRODUCTION

The basic concept of the structure of an atom is the first topic in physics. In this lesson the atomic theory is extended to semiconductors materials that are used in electronic devices such as diodes and transistors.

SILICON AND GERMANIUM ATOMS

Two types of widely used semiconductor materials are Silicon and Germanium. Both of Silicon and Germanium atoms have four free electrons. They only differ where Silicon has 14 protons in its nucleus and Germanium has 32 as shown in Fig. 3.1-1.

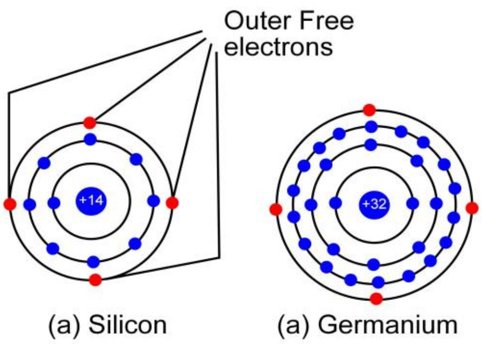


Fig. 3.1-1 Silicon and Germanium Atoms

ATOMIC BONDING

When Silicon atoms combine into molecules to form a solid material, they arrange themselves in a fixed pattern called a crystal. The atoms within the crystal structure are held together by covalent bonds, which are created by interaction of the free electrons of each atom.

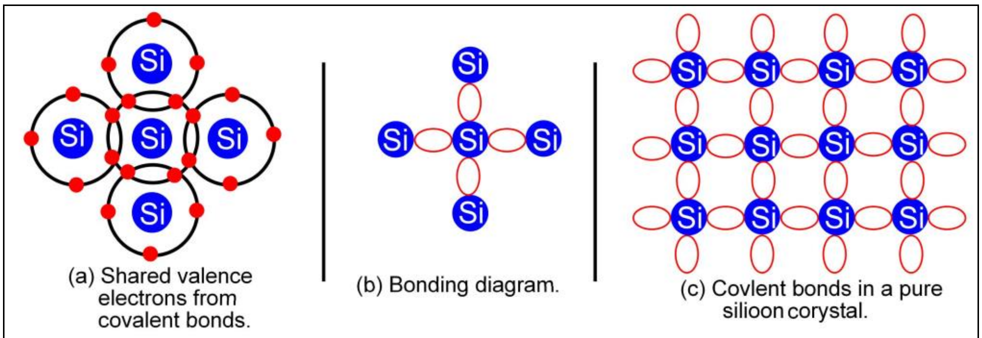


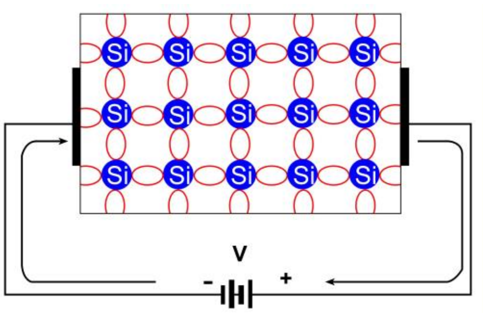
Fig. 3.1-2 Covalent Bonds in Silicon

Fig. 3.1-2 shows how each Silicon atom positions itself with four adjacent atoms. Since an atom can have up to eight electrons in its outer shell, a Silicon atom with its four valence electrons shares an electron with each of its four neighbors. This sharing of valence electrons produces the covalent bonds that hold the atoms together, because each shared electron is attracted equally by the two adjacent atoms sharing it. Covalent bonding of a pure Silicon crystal is shown in Fig. 3.1-2(c).

GERMANIUM VERSUS SILICON

Silicon is the normal semiconductor material and is used far more widely than Germanium. One reason for its wide usage is that Silicon can be used at a much higher temperature than Germanium. The study in this book concentrates on the Silicon type only.

ELECTRON AND HOLE CURRENT

When a voltage is applied across a piece of Silicon, as shown in Fig. 3.1-3, the valence (free) electrons are easily attracted toward the positive end. This movement of free electrons is one type of current in a semiconductor material, called electron current.	 Fig. 3.1-3 Free Electron Current in Silicon

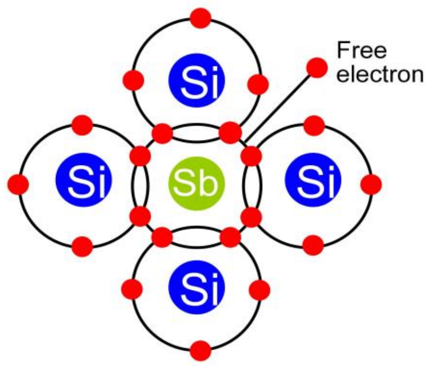
DOPING

Pure semiconductor materials do not conduct current very well because of the limited number of free electrons. Thus, the resistivity of a semiconductor is much greater than that of a conductor. The resistivity of Silicon and Germanium can be reduced and

controlled by the addition of impurities to the pure semiconductor material. This process called doping, increases the number of current carriers (electrons or holes), thus increasing the conductivity and decreasing the resistivity. The two categories of impurities are N-type and P-type.

N-TYPE SEMICONDUCTOR

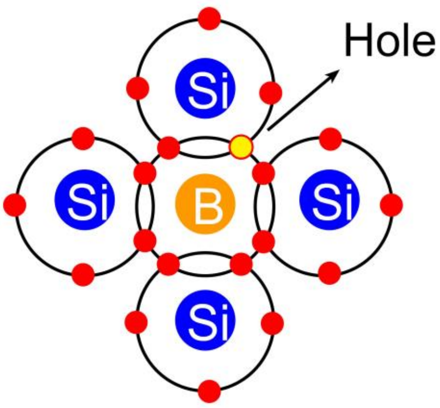
To increase the number of electrons in pure Silicon, pentavalent (atoms with 5 electrons in the outer orbit) impurity atoms are added. These are atoms with five valence electrons such as Arsenic (Ar), Phosphorus and Antimony (Sb). As illustrated in Fig. 3.1-4, each pentavalent atom (Antimony) forms covalent bonds with four adjacent Silicon atoms.

Four of the Antimony atom's valence electrons are used to form the covalent bonds, leaving one extra electron. This extra electron becomes a conduction electron because it is not attached to any atom. The number of conduction electrons can be controlled by the amount of impurity added to the Silicon.	 Fig. 3.1-4 Pentavalent of Silicon Crystal

Since most of the current carriers are electrons, Silicon (or Germanium) doped in this way is an N-type semiconductor material where the N stands for the negative charge on an electron. The electrons are called the majority carriers in N-type material. Although the great majority of current carriers in N-type material are electrons, there are some holes. Holes in an N-type material are called minority carriers.

P-TYPE SEMICONDUCTOR

To increase the number of holes in pure Silicon, Aluminum, Boron and Gallium must be added. As illustrated in Fig. 3.1-5, each trivalent (atoms with 3 electrons in the outer orbit) atom Boron (B) forms covalent bonds with four adjacent Silicon atoms.

All three of the Boron atom's valence electrons are used in the covalent bonds. Since four electrons are required, a hole is formed with each trivalent atom. The number of holes can be controlled by the amount of trivalent impurity added to the Silicon. Boron (B) impurity atom shown in the center.	 Fig. 3.1-5 Trivalent Impurity Atom in Silicon Crystal

Since most of the current carriers are holes, Silicon (or Germanium) doped in this way is called a P-type semiconductor material because holes can be thought of as positive charges, called the majority carriers in P-type material. Although the great majority of current carriers in P-type material are holes, there are some electrons called minority carriers.

PN JUNCTION DIODE

When a piece of Silicon is doped so that half is N-type and the other half is P-type, a PN junction is formed between the two regions as shown in Fig. 3.1-6(a). This device is known as a semiconductor diode. The N region has many conduction electrons and the P region has many holes as shown in Fig. 3.1-6(b). The PN junction is

fundamental to the operation not only of diodes but also of transistors and other solid state devices.

The depletion layer is formed when connecting P to N type as shown in Fig. 3.1-6(c). When an equilibrium condition is reached, the depletion layer has widened to a point where no more electrons can cross the PN junction. Depletion layer or barrier region forms a barrier potential and these potentials are:

a. Silicon diode barrier potential = 0.6 to 0.7 volts

b. Germanium diode barrier potential = 0.2 to 0.3 volts

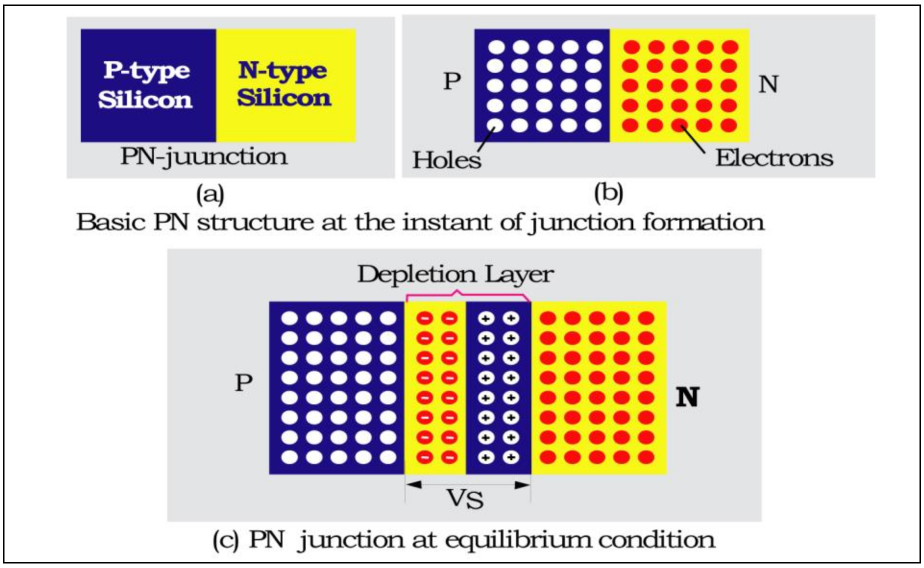


Fig. 3.1-6 PN Junction Diode

There are 2 biasing conditions for the standard Junction Diode:

- Forward Bias - The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of Decreasing the PN-junction width.
- Reverse Bias - The voltage potential is connected negative, (-ve) to the P type material and positive, (+ve) to the N-type material across the diode which has the effect of Increasing the PN-junction width.

FORWARD BIAS

When a diode is connected in a Forward Bias condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material as shown in Fig. 3.1-7. If this external voltage becomes greater than the value of the potential barrier, 0.7 volts for Silicon and 0.3 volts for Germanium, the potential barriers opposition will be overcome and current will start to flow as the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this "knee" voltage and high current flow through the diode with little increase in the external voltage as shown in Fig. 3.1-8.

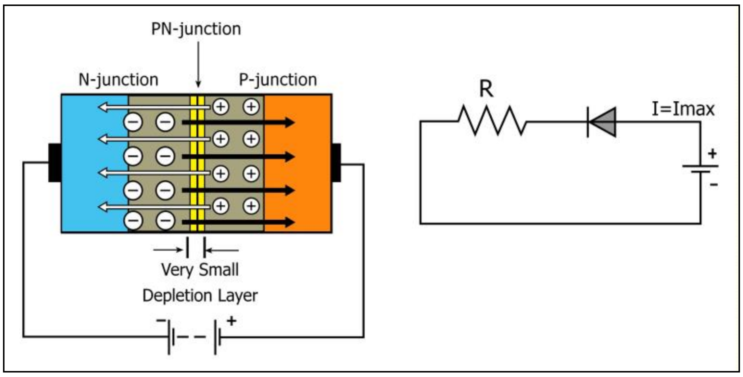


Fig. 3.1-7 Forward bias junction diode showing reduction in the depletion layer

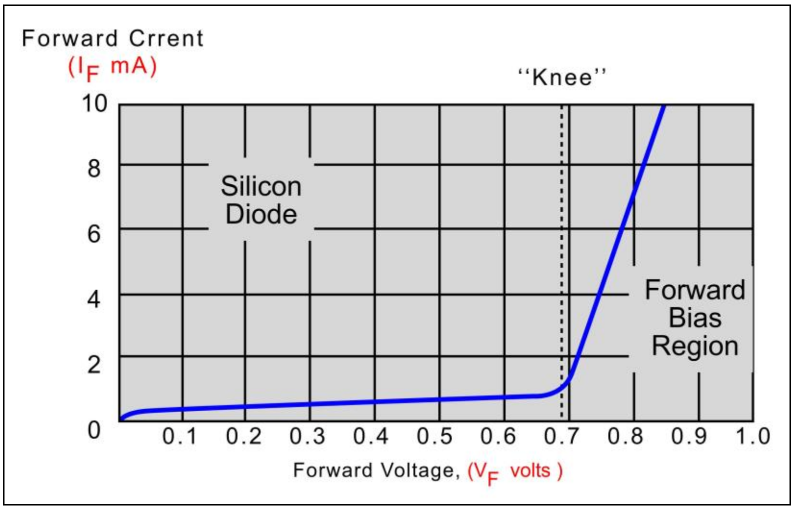


Fig. 3.1-8 Forward Characteristics Curve for a Diode

This results in the depletion layer becoming very thin and narrow and which now represents a low impedance path thereby producing a very small potential barrier and allowing high currents to flow. The point at which this takes place is represented on the static I-V characteristics curve above as the "knee" point.

This condition represents the low resistance direction in a PN-junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at about 0.7V. Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, resistors are used in series with the device to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in failure of the device. The diode forward resistance may have the range of (1Ω to 200Ω).

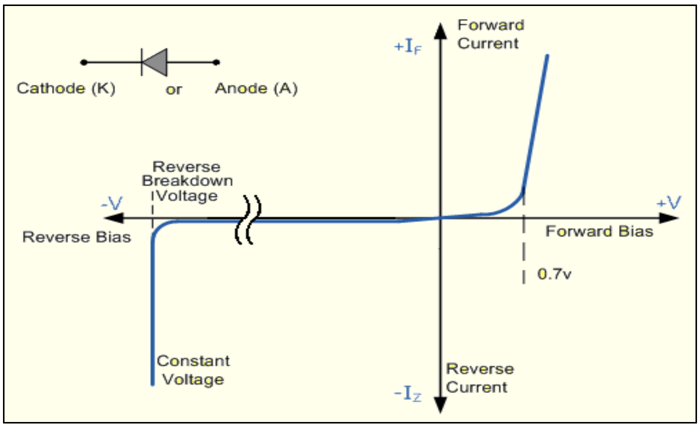


Fig. 3.1-9 Forward/Reverse Diode Characteristic Curve

REVERSE BIAS

When a diode is connected in a Reverse Bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material. The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode as shown in Fig. 3.1-10. The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material and the PN material looks very high resistance.

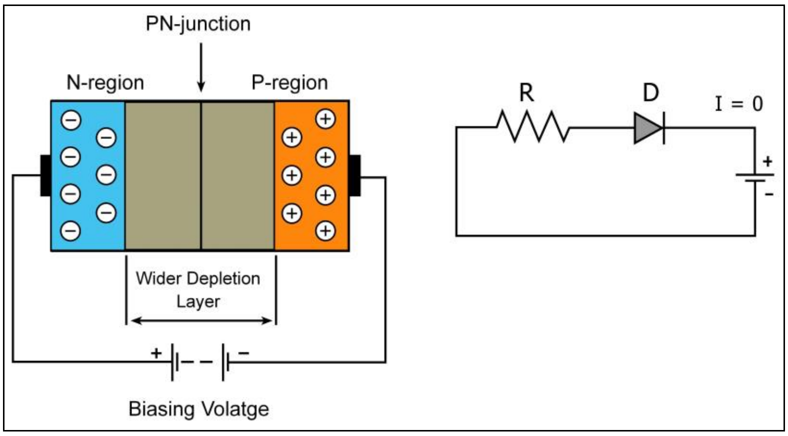


Fig. 3.1-10 A Reverse Biased Junction showing the Increase in the Depletion Layer

This condition represents the high resistance direction of a PN-junction and practically zero current flows through the diode with an increase in bias voltage. However, a very small leakage current does flow through the junction which can be measured in microamperes, (μA). One final point, if the reverse bias voltage V_R applied to the junction is increased to a sufficiently high enough value, it will cause the PN-junction to overheat and fail. This may cause the diode to become shorted which will result in maximum circuit current to Ohm's Law shown in the reverse characteristics curve, as shown in Fig. 3.1-11.

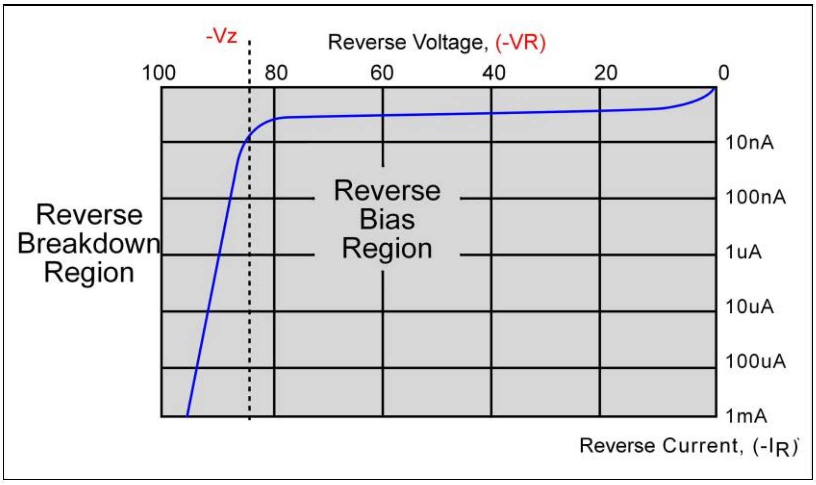


Fig. 3.1-11 Reverse Characteristics Curve for a Diode

Sometimes this breakdown effect has practical applications in voltage stabilizing circuits where a series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as Zener Diodes and are discussed in a later tutorial.

DIODE APPLICATIONS

The semiconductor diode is used in electronics as a rectifier, detector, clamper, limiter and logic switch. Some diodes are manufactured to carry hundreds of amperes of current. Others may be required to detect extremely weak radio signals, while still others may be designed to switch rapidly from the conducting to the non-conducting states. The ideal diode exhibits the same characteristics as a switch (Fig. 3.1-12). When biased in the forward direction, it has zero resistance (short circuit) and maximum current can flow through it. When biased in the reverse direction, it has infinite resistance (open-circuit) letting zero current through it.

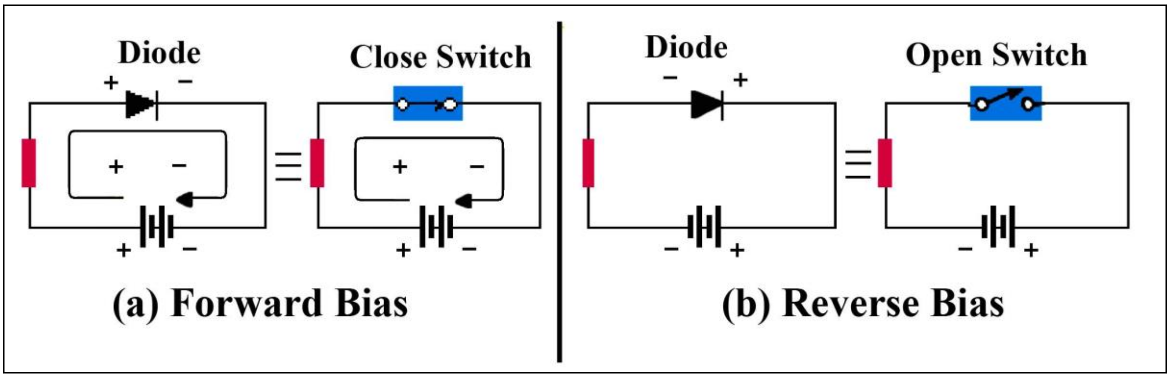


Fig. 3.1-12 Ideal Diode as Switch

TYPICAL DIODES

Some typical diodes are shown in Fig. 3.1-13 to illustrate the variety of physical structures as discrete or integrated components identification.

Fig. 3.1-13 Typical Diodes

DIODE TESTING WITH MULTI-METER

The diode test will check a diode's barrier voltage. To test diodes with this feature you must place the selector switch on the diode test position as shown in Fig. 3.1-14. Remember, a diode should only allow current to pass in one direction.

Fig. 3.1-14 Multi-meter position during diode test

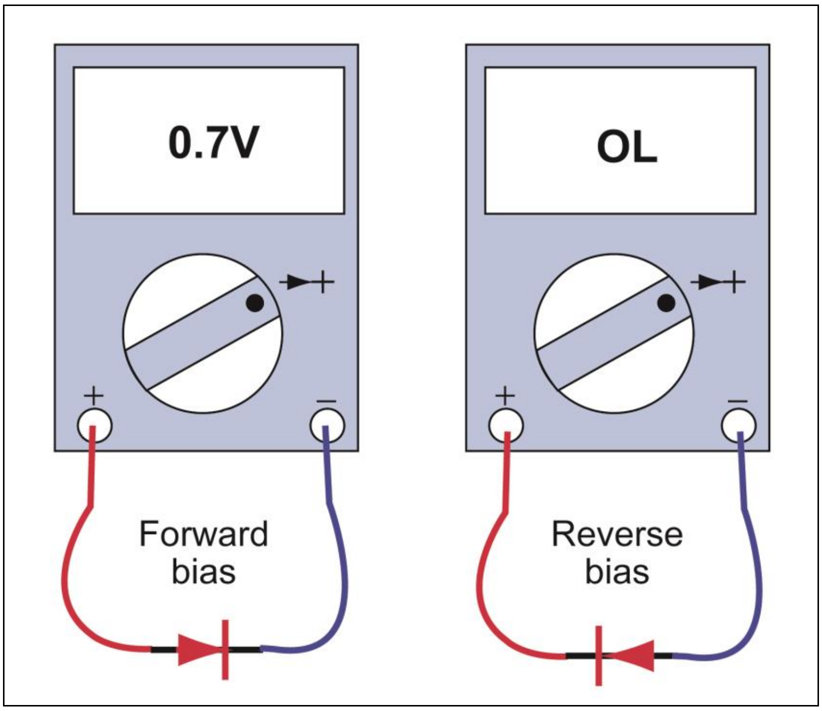


Fig. 3.1-15 Diode Testing Using Digital Multi-meter

The meter's leads must be positioned as shown in Fig. 3.1-14. The meter leads must be connected with the diode as shown in Fig. 3.1-15. The meter will display the barrier voltage of the diode. The expected result on the multi-meter screen will be 0.7V at the diode in the forward bias or to show OL (Over Load) when the diode in the reverse direction. Any reading on the multi-meter except (0.7V or OL) means that the diode is defected.

HALF-WAVE RECTIFIER

One of the most famous diode applications is the rectifier circuit. Rectification is the basic circuit to convert AC to DC, there are two types of rectifier; half wave rectifier and full wave rectifier. In the positive half cycle, the supply will be passed to the sine wave, the diode will be forward bias and it appears very low resistance. In the negative half cycle the supply stop passing the wave, the diode will be reverse bias and it appears very high resistance. Half wave rectifier uses normally single diode as shown in Fig. 3.1-16. The anode terminal of the diode is connected to the AC supply, while the cathode terminal is connected to the load. The diode allows to the positive half cycles only to pass through the load and prevent the negative half cycles from passing.

The average output voltage: $V_{AVG} = V_P / \pi$ When, $\pi = 3.14$

NOTE

The output signal frequency is equal to the input signal frequency.

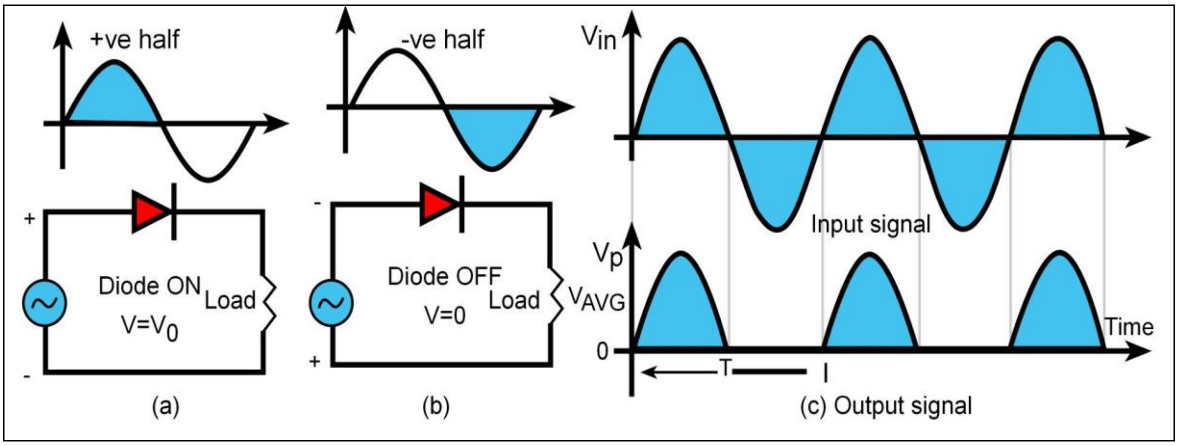
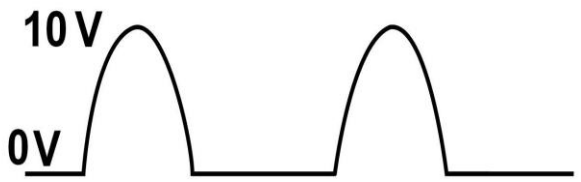


Fig. 3.1-16 Operation of Half-Wave Rectifier

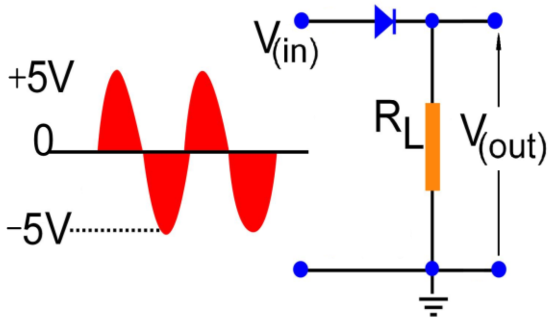
Note that in half wave rectifier during positive half cycle, the diode exhibits 0.7V voltage drop and this value is subtracted from the output voltage.

Note that in half wave rectifier during negative half cycle, all the supply voltage is applies on the diode and nothing is remained to get output.

EXAMPLE 5.1-1 What is the average (DC) value of the half-wave rectified voltage waveform in Fig. 3.1-17?	 Fig. 3.1-17 Half-Wave Rectified Signal

SOLUTION

$$V_{AVG} = \frac{V_P}{\pi} = \frac{10}{\pi} = 3.183\,V$$

EXAMPLE 5-1-2 Determine the peak output voltage of the Silicon rectifier circuit in Fig. 3.1-18 for the indicated input voltage.	 Fig. 3.1-18 Peak Half-Wave Output Voltage

SOLUTION

The peak half-wave output voltage is:

$V_P = 5\text{ V} – 0.7\text{ V} = 4.3\text{ V}$

FULL WAVE RECTIFIER

Full wave rectifier is widely used in most applications, it uses four diodes as shown in Fig. 3.1-19 and Fig. 3.1-20. In this circuit the negative half cyles are reversed to become positive and appear on the average output voltage. $V_{AVG} = 2V_P / \pi$

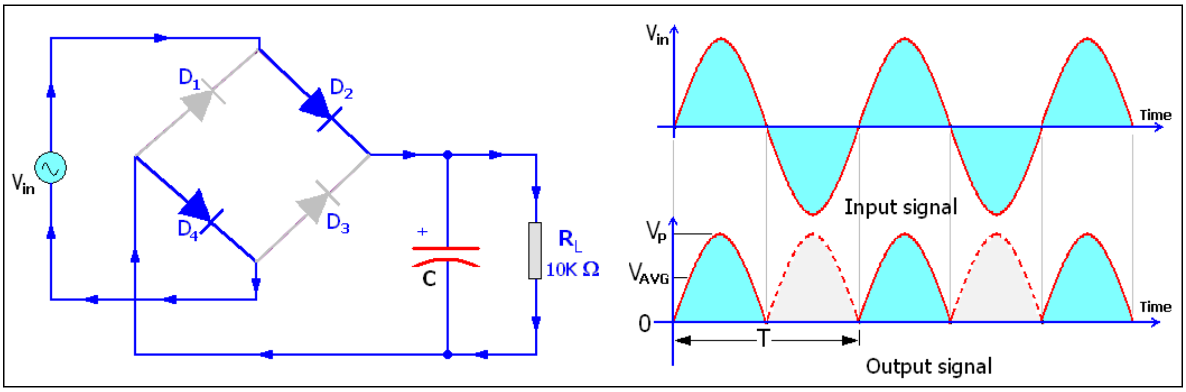


Fig. 3.1-19 Full Wave Rectifier Circuit During Positive Half Cycle

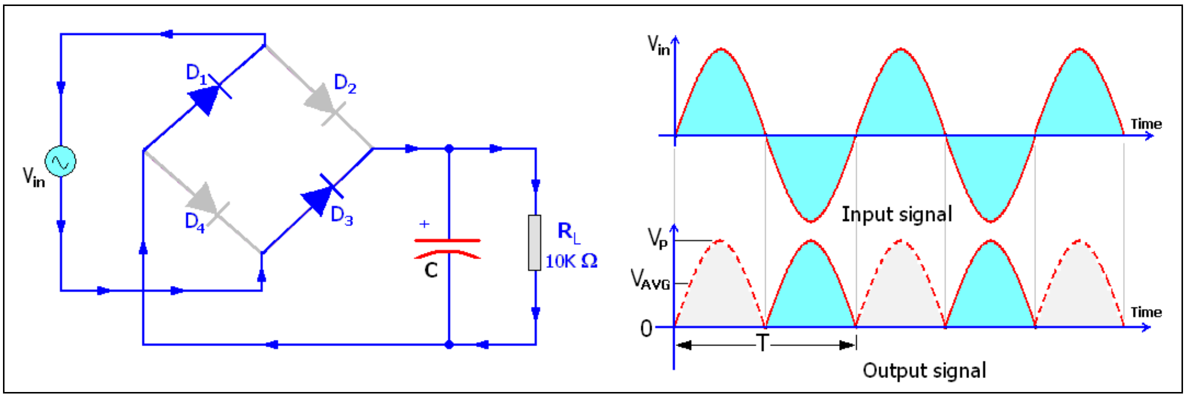


Fig. 3.1-20 Full Wave Rectifier Circuit During Negative Half Cycle

Note: at full wave rectifier during positive half cycle, the diodes apply voltage drop of 1.4V this value is subtracted from the output voltage.

Note: at full wave rectifier during negative half cycle, the diode applies all the input voltage and nothing is remained to get output. Note the output signal frequency is twice the input signal frequency.

ZENER DIODE

The zener diode is used for voltage regulation, especially, in regulated power supply, control circuits, protective relays and UPS systems. The zener diode is designed to conduct current in the reverse direction when the input voltage tends to increase over the load output voltage. It is selected from data sheet to fix the load voltage at a

certain required value and any increase in the input voltage is applied on a resistance in series with the zener diode as shown in Fig. 3.1-21.

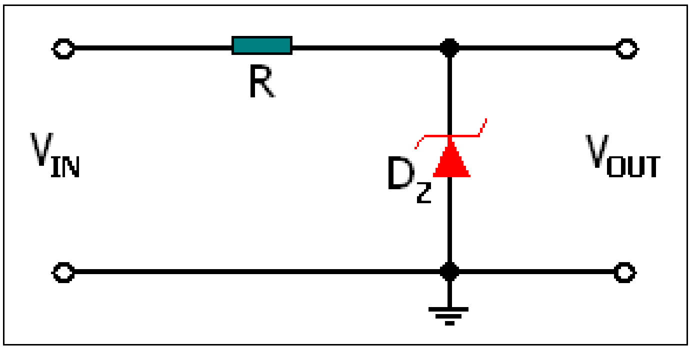


Fig. 3.1-21 Typical Connection of Zener Diode

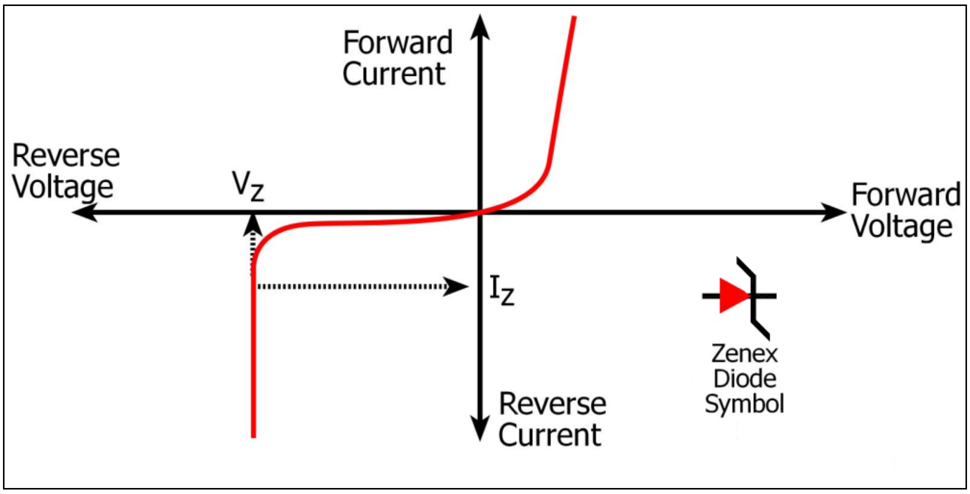
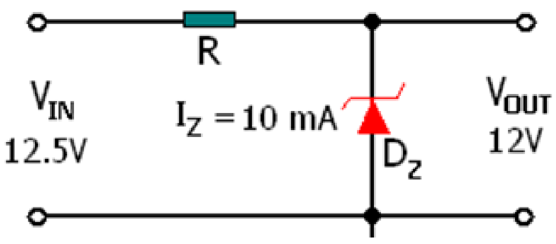


Fig. 3.1-22 Typical V-I Characteristics Curve of Zener Diode

Zener diode characteristic, as shown in Fig. 3.1-22, is illustrated when the zener breakdown voltage (V_Z) causes a sudden flow of zener current (I_Z) when the zener diode resistance (R_Z) decrease to a lower value. The ideal zener diode has infinite resistance and conducts no current at normal operation, but under overvoltage condition a fixed zener voltage appears at the output depending on the zener current designed from the data sheet and characteristic of the diode.

EXAMPLE 5.1-3

Determine the required series resistance value to fix 12V on the output of the circuit shown in Fig. 3.1-23, if the zener current at breakdown is set to be 10mA at the input voltage of 12.5V.	 Fig. 3.1-23 Example 3.1-3

SOLUTION

$V_{IN} = V_Z + I_Z R$ and $V_{OUT} = V_Z$

$12.5 = 12 + 10mA \times R$

Then $R = (12.5 - 12) \times 1000/ 10 = 50\Omega$

SUMMARY

- An atom is described as a nucleus containing protons and neutrons orbited by electrons.
- Protons are positive charge, neutrons are neutral and electrons are negative charge.
- The outer orbit contains free electrons to move to other atoms.
- Silicon and Germanium are widely uses in semiconductor materials.
- Atoms within a crystal structure are held together with covalent bonds.
- The process of adding impurities to pure semiconductor to increase and control conductivity is called doping.
- A P-type semiconductor is doped with trivalent (atoms with 3 electrons in the outer orbit) impurity atoms.
- The P-type semiconductor is doped with trivalent impurity atoms.

- The N-type semiconductor is doped with pentavalent impurity atoms.
- The depletion layer is a region adjacent to the PN junction containing no majority carriers.
- Forward bias permits majority carrier current through the PN junction.
- Reverse bias prevents majority carrier current.
- A PN structure is called a diode.
- Reverse breakdown occurs when the reverse-biased voltage exceeds rated value.
- The single diode in a half-wave rectifier conducts the positive half cycle only.
- The average (DC) value of a half-wave rectifier signal is 0.318 or ($1/\pi$) times its peak-value.
- The Zener diode operates in reverse breakdown.
- A Zener diode maintains an essentially constant voltage across its terminals over a specified range of Zener diode.
- Zener diodes are used as shunt voltage regulators.
- Regulation of output voltage over range of input voltages is called input or line regulation.
- Regulation of output voltage over range of load current is called load regulation.

FORMULAS

$$V_{AVG} = \frac{V_P}{\pi}$$

Where: V_{AVG} =Average output voltage of HW rectifier

V_P = Peak output voltage

$V_{OUT} = V_P - 0.7V$

For zener diode: $V_{IN} = V_Z + I_Z R$

Where: R = series resistance

V_Z = Zener fixed output voltage

I_Z = Zener current at breakdown zener voltage happen

GLOSSARY

Covalent	Sharing
Doping	Adding impurities to the pure semiconductor material, thus increasing the conductivity and decreasing the resistivity
Minority carriers	Little amount of holes
Depletion layer	Isolation area
Valence Electrons	Electrons on the outer orbit of the atom
PN Junction	Joining between P-material and N-material
Reverse Biasing	A positive voltage is applied to the cathode
Forward Biasing	A negative voltage is applied to the cathode
Potential barrier	Silicon/Germanium diode drop to be overcome before and current can flow when forward-biased by external voltage
Multi-meter	An instrument to measure current, voltage and resistance
Regulation	Fixing the output voltage at constant value
Smoothing	Let the voltage straight without repels
Pentavalent	Atoms with 5 electrons in the outer orbit
Trivalent	Atoms with 3 electrons in the outer orbit

REVIEW EXERCISE

1. What is the current in the circuit of Fig. 3.1-24, if the total forward resistance of the Silicon diode is 10Ω?

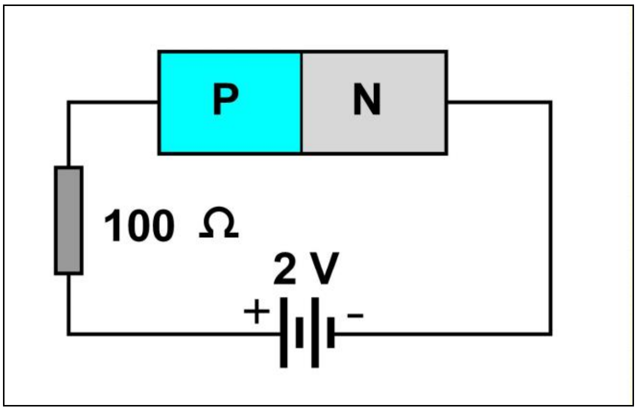


Fig. 3.1-24

2. In each circuit of Fig. 3.1-25, indicate whether the diode is forward-biased or reverse-biased. What is the voltage across each Silicon diode?

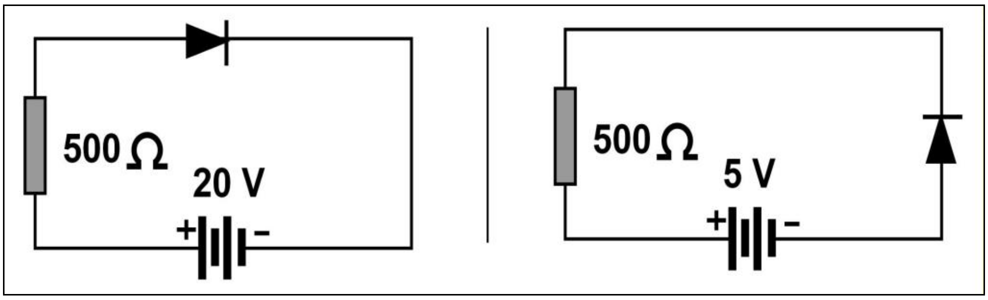


Fig. 3.1-25

3. What is the average value of the voltage shown in Fig. 3.1-26?

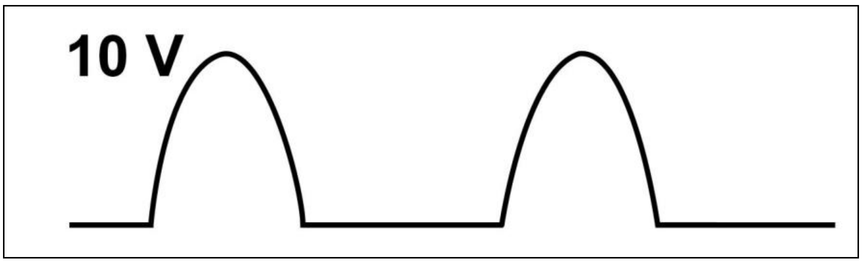


Fig. 3.1-26

4. What should be the adjusted value of R in Fig. 3.1-27 to make I_Z = 40 mA? Assume that V_Z = 12 V.

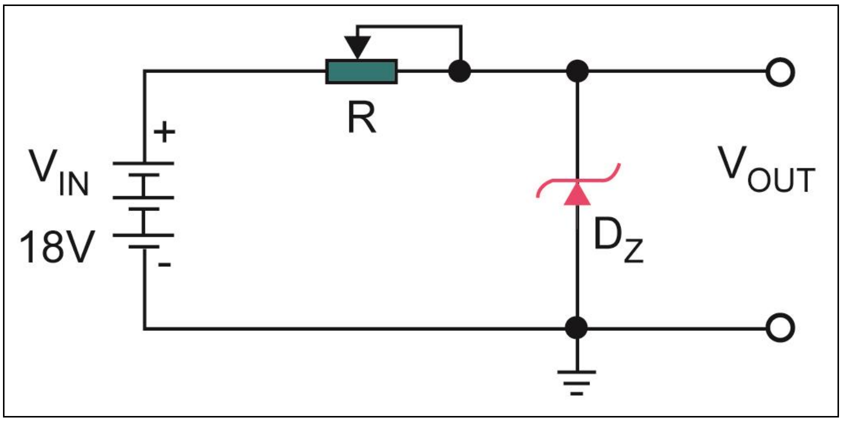


Fig. 3.1-27

TASK 3.1-1

SEMICONDUCTOR DIODE

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Demonstrate practical testing of semiconductor diodes.

TOOLS, EQUIPMENT & MATERIALS

- Digital multi-meter.
- Silicon signal diode.

PROCEDURE

1. Set the digital multi-meter on semiconductor test position as shown in Fig. 1-1. Make sure that the positive terminal (Red lead) of the digital multi-meter is connected to the anode terminal of the diode, and the negative terminal (black lead) is connected to the cathode terminal of the diode.

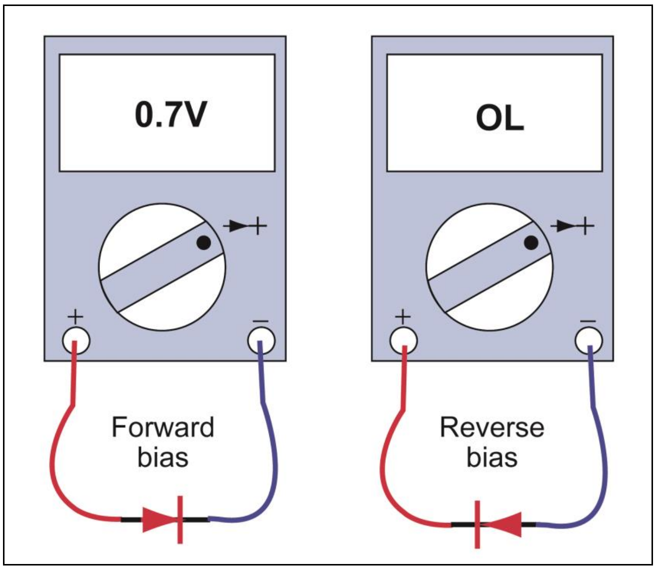


Fig. 1-1 Typical Test Connections to Check Forward and Reverse Diode

2. The multi-meter now measures the forward voltage drop of the diode, which must be 0.7V for silicon diode and 0.2V for germanium diode.
3. Reverse the diode terminals and repeat step 3 displaying OL on the multi-meter screen. Any low measure on the multi-meter means that the diode is defective.

TASK 3.1-2
HALF WAVE & FULL WAVE RECTIFIERS

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Demonstrate the diode operation in half wave rectifier circuit.
- Demonstrate the diode operation in full wave rectifier circuit.

TOOLS, EQUIPMENT AND MATERIALS

- 1 -ETW-3600A Electronic Design Experimenter
- 1 -Oscilloscope (dual trace)
- 1 –Digital multi-meter
- 4 -Silicon signal diodes
- 1 -100 μF, 50 volt, electrolytic capacitor
- 2 -10K, 1/2-watt

PROCEDURE

1. With the ETW-3600 turned off, construct the circuit shown in Fig. 2-1. Make certain that the banded end (cathode terminal) of the diode connects to R_L.

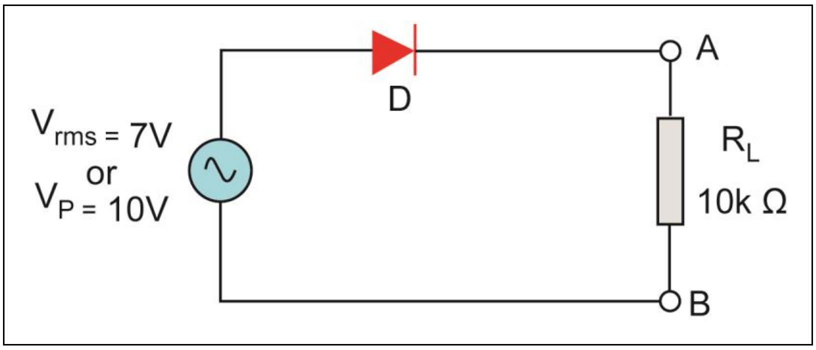
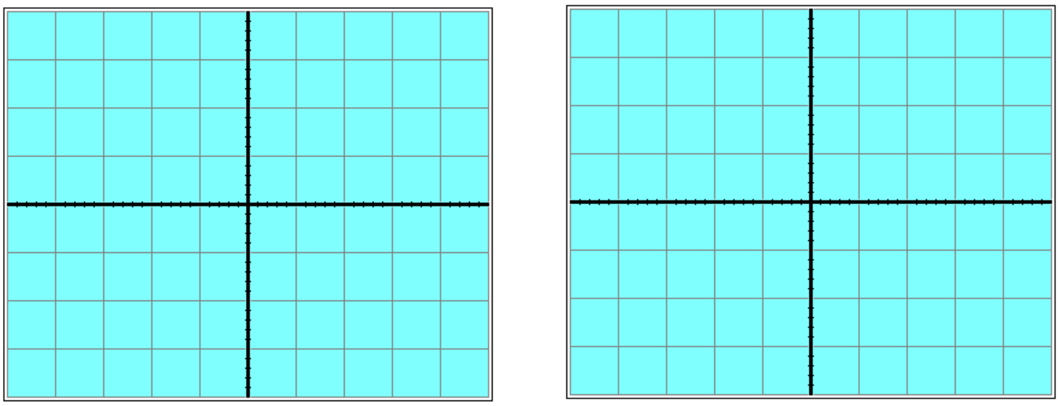


Fig. 2-1 Half Wave Rectifier

2. Turn on the oscilloscope and set the controls as follows
   - **TIME/CM -** Selector to 5 ms position
   - **AC/GND/DC -** Input switch to the AC position
   - **VOLTS/CM -** Selectors to 5 volts
3. Turn on the ETW-3600 and adjust the output of the trainer by the multi-meter to be 7V (r.m.s). By measuring these value on the Oscilloscope you should found 10V as peak value. Connect the ground lead of the oscilloscope to point B in the circuit. Connect CH 1 scope probe to the unbanded end of the diode to measure the input AC. Connect CH 2 to point A to measure the output DC. Sketch the waveforms in the space provided in Fig. 2-2(a). The distortion on the power transformer in the ET-3100 trainer. Measure the time of one cycle of the input and compute the input and output frequencies. Draw 2 cycles of the input and output waveforms in the space provided in Fig. 2-2(b).

   T = __________ms **f =** **__________Hz**



(a) CH1 Time of one cycle (b) CH2 Time of one cycle

Fig. 2-2 Drawing the Waveforms

4. Compute and measure the peak-to-peak value of the AC signals.

   V_{P-P} (CH 1) = ___________volts **V_{P-P} (CH 2) = ___________volts**
5. Adjust the AVO meter to measure DC Volt and connect between points A & B.

   V_{OUT} = __________ volts

6. Switch off the trainer source and connect the electrolytic smoothing capacitor shunt with the load resistance. Reconnect the supply and note the effect of adding smoothing capacitor to the rectifier circuit.

NOTE

- ***Electrolytic capacitor has positive polarity must be connected to the cathode terminal and negative polarity is connected to ground.***
- ***When using the two channels of the oscilloscope at the same time, don't connect the ground terminal of channel 2 (keep it floating).***

7. Turn off the power supply and reconnect the full wave rectifier circuit of Fig. 2-3 without capacitor and adjust the output of the trainer by the multi-meter to be 7V (r.m.s). Measure these value on the Oscilloscope you should found 10V as peak value. Connect the ground lead of the oscilloscope to point B in the circuit. Connect CH 1 scope probe to the cathode end of the diode to measure the input AC. Connect CH 2 to point A to measure the output DC.

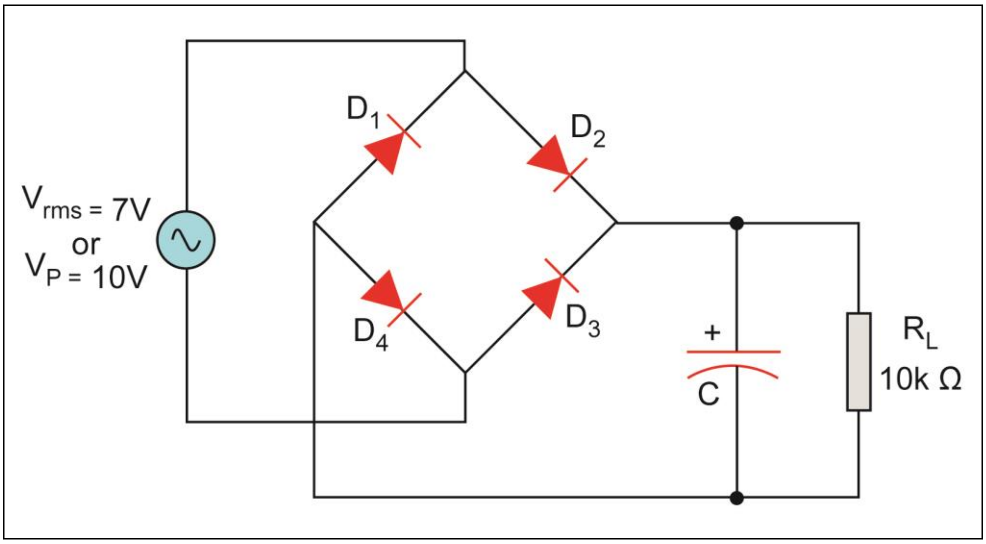


Fig. 2-3 Full Wave Rectifier

8. Sketch the waveforms in the space provided in Fig. 2-4(a). Measure the time of one cycle of the input and compute the input and output frequencies. Draw 2 cycles of the input and output waveforms in Fig. 2-4(b).

T = __________**Ms** **f =** __________**Hz**

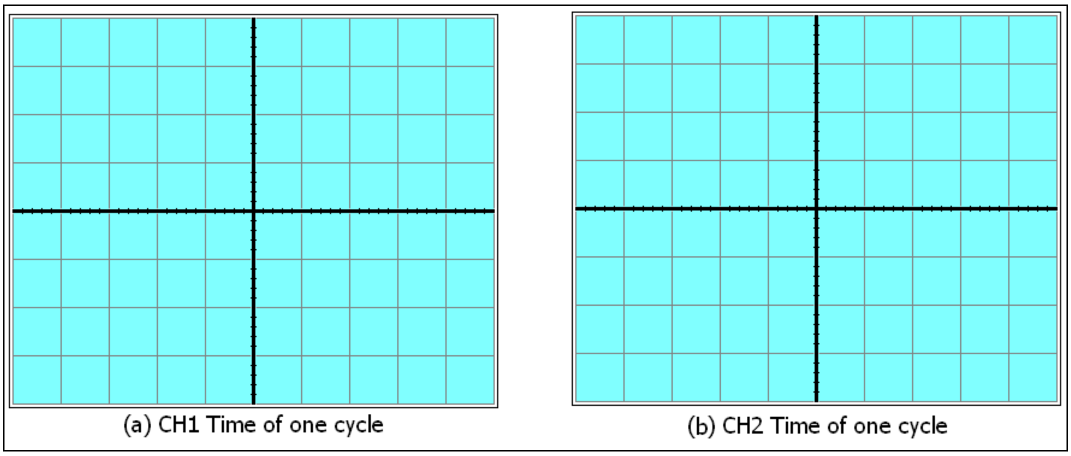


Fig. 2-4 Drawing the Waveforms

9. Compute and measure the peak-to-peak value of the AC signals.

   V_{P-P} (CH 1) = ___________volts **V_{P-P} (CH 2) = ___________volts**

10. Adjust the AVO meter to measure DC Volt and connect between points A & B.

    V_{OUT} = __________ volts

11. Switch off the trainer source and connect the electrolytic smoothing capacitor shunt with the load resistance. Reconnect the supply and note the effect of adding smoothing capacitor to the rectifier circuit.

TASK 3.1-3
ZENER DIODE

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Demonstrate zener diode application as a voltage regulator.

TOOLS, EQUIPMENT AND MATERIALS

- Heathkit Electronic Design Experimenter, ETW 3600.
- Digital multi-meter.
- Potentiometer, 100KΩ.
- 100Ω, Resistor.
- Zener Diode, 5.1 volts.

PROCEDURE

1. Connect the circuit, as shown in Fig. 3-1, using the 100KΩ potentiometer on the Heathkit Experimenter.

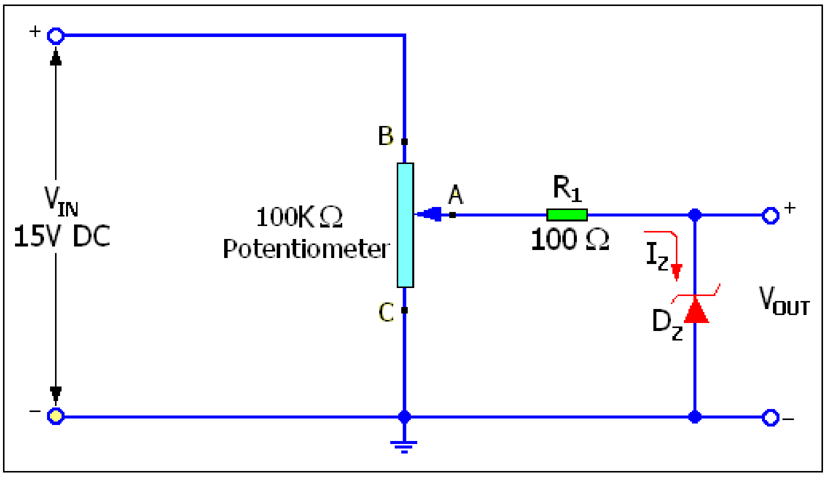
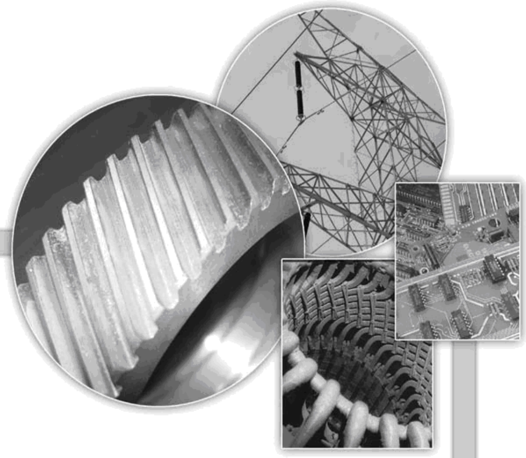


Fig. 3-1 Experimental Circuit for Task 3

2. Turn the positive (+) voltage control fully clockwise so that the full power supply voltage, approximately 15 VDC is applied to the 100KΩ potentiometer terminals B & C.
3. Adjust the 100KΩ potentiometer knob to let resistance between point A and point C $R_{AC} = 0$, so the measured voltage on the output V_{OUT} will be zero too.
4. Slowly increase the potentiometer resistance R_{AC} and monitor the output voltage, result in $V_{OUT} = V_A$.
5. The voltage drop on the resistor R_1 equals zero, and that means zener current $I_Z = 0$.
6. Step by step increase the potentiometer resistance R_{AC} until the measured output voltage reaches 5.1V.
7. The voltage drop on the resistor R_1 still zero, and that means zener current $I_Z = 0$.
8. Continue to increase the potentiometer resistance R_{AC}. Resulting that, the voltage V_A increases while the output voltage V_{OUT} still constant at 5.1V.
9. In this case the voltage drop on the resistance R_1 will start to increase, that mean the zener diode start operation in the reverse direction and hence I_Z will not equal zero.

CONCLUSION

Zener diode is used as voltage regulation to fix load voltage of power supply at the required operating voltage, and the zener diode is selected by its specified zener voltage.



LESSON 3.2

BIPOLAR JUNCTION TRANSISTORS

LESSON 3.2

BIPOLAR JUNCTION TRANSISTORS

OVERVIEW

This lesson introduces the bipolar transistor testing and biasing techniques for DC circuit configurations.

OBJECTIVES

Upon completion of this lesson the trainees will be able to:

- Identify the bipolar transistor terminals, styles, data sheet and testing.
- Verify transistor biasing calculations.
- Illustrate transistor biasing using voltage divider.
- Demonstrate transistor test using multi-meter.

Task 3.2-1: Bipolar Transistor Testing

INTRODUCTION

It was learned from the previous lesson that a semiconductor diode is basically a two-element device containing a single PN junction. The N-type material, the cathode, serves as the negative terminal, while the P-type material, the anode, serves as the positive terminal.

When another section or region of P or N type material is added to a PN diode junction to form three sections, a three-element device, containing two junctions, (J_1 & J_2) is produced. This three-element device is a bipolar transistor with the emitter (E), the base (B) and the collector (C), as shown in Fig. 3.2-1 The term bipolar refers to the use of both holes and electrons as carriers in the transistor structure.

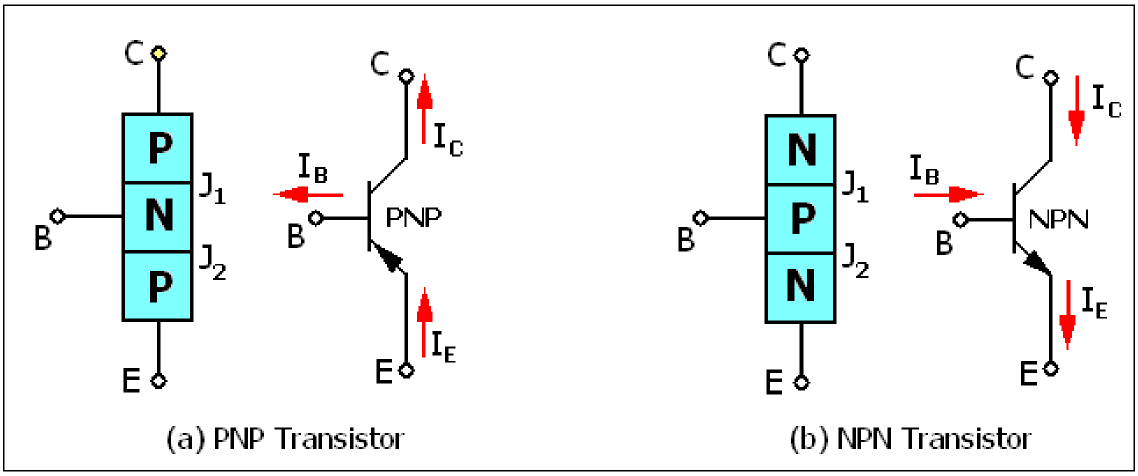


Fig. 3.2-1 PNP & NPN Transistor Structure & Symbols

It is cleared from Fig. 3.2-1 the directions of each terminal current I_C, I_B and I_E if it is inter or out to the transistor junctions in each of the PNP or NPN types.

Transistors are classified by the arrangement of the P and N type materials and are either PNP or NPN types. The connections for PNP, NPN transistors and their symbols are shown in Fig. 3.2-1. The PN junction joining the base region and the emitter region is called the Base-Emitter junction. The junction joining the base region and the collector region is called the Collector-Base junction, as indicated. A wire lead

connects to each of the three regions, as shown. These leads are labeled E, B and C for Emitter, Base and Collector, respectively.

TRANSISTOR BIASING

In order for the transistor to operate properly as an amplifier, the two PN junctions must be correctly biased with external voltages. We will use the NPN transistor to illustrate transistor biasing. The operation of the PNP is the same as for the NPN except that the roles of the electrons and holes, the bias voltage polarities and the current directions are all reversed, as shown in Fig. 3.2-2. Notice that in both cases the Base-Emitter (B-E) junction is forward-biased and the Collector-Base (C-B) junction is reverse-biased.

$\mathbf{I_E = I_C + I_B}$

When: I_C = Collector current

I_B = Base current

I_E = Emitter current

$\mathbf{I_B}$ is very small compared to $\mathbf{I_E}$ or $\mathbf{I_C}$. These direct currents are also related by two parameters: the collector current gain **(α_{DC})** and the base current gain **(β_{DC})**.

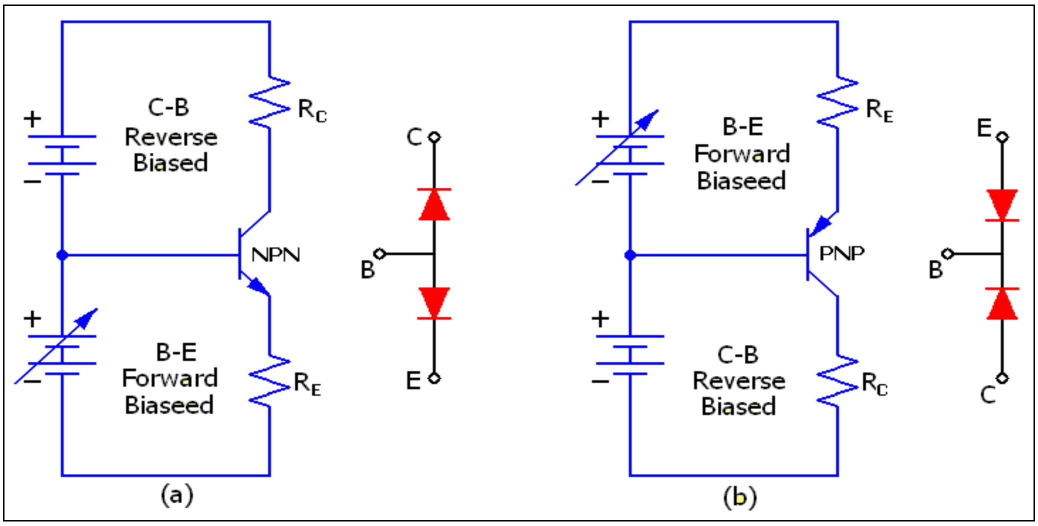


Fig. 3.2-2 NPN & PNP Transistor Biasing

$\mathbf{I_C = \alpha_{DC} \times I_E}$

Where: α_{DC} typically has a value between 0.95 and 0.99.

The collector current is related to the base current by β_{DC}.

$\mathbf{I_C = \beta_{DC} \times I_B}$

Where: β_{DC} typically has a value between 20 and 200.

BASE VOLTAGE BIASING

The three DC voltages for the biased transistor in Fig. 3.2-3 are the emitter voltage (V_E), the collector voltage (V_C) and the base voltage (V_B) measured with respect to ground. The collector voltage is equal to the DC supply voltage (V_{CC}), less the drop across R_C.

$\mathbf{V_C = V_{CC} - I_C R_C}$

The emitter voltage (V_E) is the emitter current I_E times the emitter resistor R_E:

The base voltage is equal to the emitter voltage plus the Base-Emitter junction barrier potential (V_{BE}), which is about 0.7V for a silicon transistor:

$\mathbf{V_B = V_E + V_{BE} = V_{BB} - (I_B \times R_B)}$

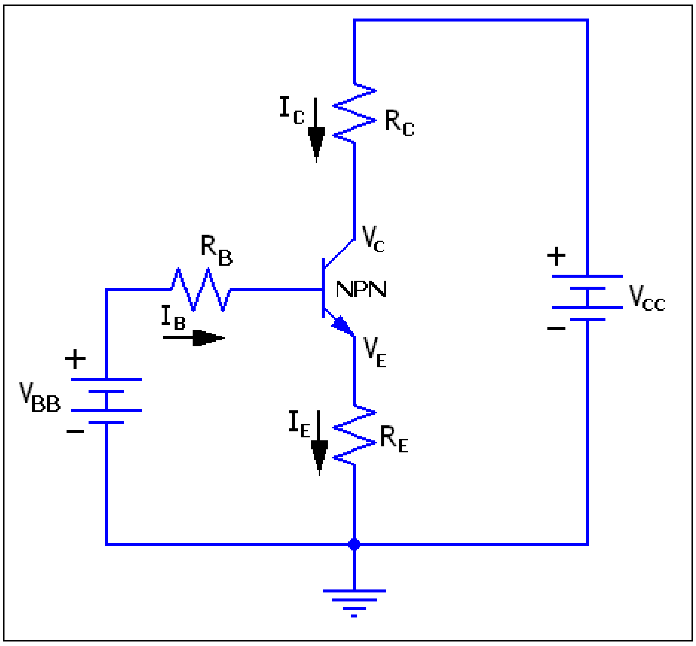


Fig. 3-2-3 Transistor Base Biasing

In the configuration circuit of Fig. 3.2-3, emitter is the common terminal. If the value of the emitter resistor R_E is 0Ω, the emitter voltage, $V_E = 0$ V.

EXAMPLE 5.2-1

Find I_B, I_C, I_E, V_B and V_C in the circuit shown in Fig. 3.2-4, where β_{DC} is 50.

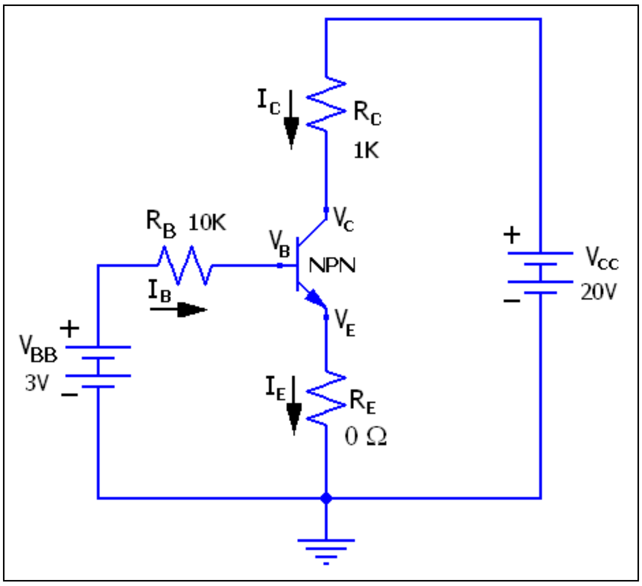


Fig. 3.2-4 Transistor Biasing Example

SOLUTION

Since R_E is 0Ω, V_E is ground, $V_B = 0.7$ V

The drop across R_B is: $V_{BB} - V_B = 3V - 0.7V = 2.3V$

So I_B is calculated as follows:

$$I_B = \frac{V_{BB} - V_B}{R_B} = \frac{3V - 0.7V}{10K} = 0.23\,mA$$

$I_C = \beta_{DC} \times I_B = 50(0.23\text{ mA}) = 11.5\text{ mA}$

$I_E = I_C + I_B = 11.5\text{ mA} + 0.23\text{ mA} = 11.73\text{ mA}$

$V_B = V_{BE} + V_E$, when $R_E = 0\Omega$, then $V_E = 0V$, then $V_B = V_{BE} = 0.7V$

$V_C = V_{CC} - I_C \times R_C = 20\text{ V} - (11.5\text{ mA}) \times (1\text{ K}\Omega) = 8.5\text{ V}$

VOLTAGE DIVIDER BIASING

One of the most common bias arrangements in transistor circuits is the voltage divider bias. This configuration uses only a single DC source to provide forward-reverse bias to the transistor, as shown in Fig. 3.2-5. Resistors R_1 and R_2 form a voltage divider that provides the base bias voltage. Resistor R_E allows the emitter to rise above ground potential.

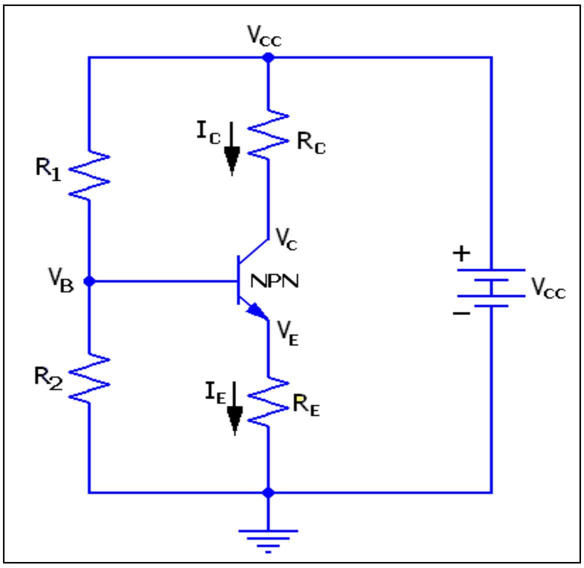


Fig. 3.2-5 Voltage-Divider Biasing

The voltage divider network (R_1 and R_2 in parallel) biases the Base-Emitter junction by the parallel equivalent resistance viewed from the base of the transistor. This equivalent resistance is used in determining the exact base bias voltage.

BASE VOLTAGE

For approximation, using the voltage divider formula, the following equation gives the approximate base voltage for the circuit in Fig. 3.2-5, assuming very small I_B as compared to I_C.

$$\mathbf{V_B = R_2 \times V_{CC} / (R_1 + R_2)}$$

Once you have determined the base voltage, you can determine the emitter voltage V_E (for an NPN transistor) as follows: $\mathbf{V_E = V_B - 0.7\ V}$

EXAMPLE 5.2-2

For the voltage divider biasing circuit of Fig. 3.2-6; determine each of the following:

a.- Base voltage V_B.

b.- Collector voltage V_C

c.- Collector to emitter voltage V_{CE}

d.- Base current I_B

e.- Emitter current I_E

e.- Emitter current I_E

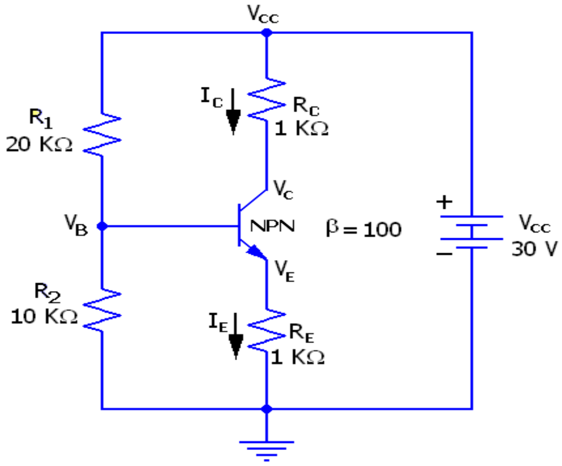


Fig. 3.2-6 Example 3.2-2

SOLUTION

$$V_B \approx \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{30V}{20K + 10K} \times 10K = 10V$$ Then,

$V_E = V_B - 0.7V = 10V - 0.7V = 9.3V$

Now that we know VE, we can find IE by Ohm's law:

$$I_E = \frac{V_E}{R_E} = \frac{9.3K}{1K} = 0.0093A = 9.3mA$$

Since α_{DC} is so close to 1 for most transistors, it is a good approximation to assume that $I_C = I_E$. Thus, $I_C \approx 9.3$ mA

Using the collector current equation $I_C = \beta_{DC} \times I_B$ and solving for I_B, we get:

$$I_B = \frac{I_C}{\beta_{dc}} = \frac{9.3mA}{100} = 0.093mA$$ Now that we know I_C, we can find V_C:

$V_C = V_{CC} - I_C \times R_C = 30\text{ V} - (9.3\text{ mA} \times 1K) = 30\text{ V} - 9.3\text{ V} = 20.7\text{ V}$

Since V_{CE} is the Collector-Emitter voltage, it is the difference of V_C and V_E:

$V_{CE} = V_C - V_E = 20.7\text{ V} - 9.3\text{ V} = 11.4\text{ V}$

TRANSISTOR TESTING

An ohmmeter can be used to test the base-to-emitter PN junction and the base-to-collector PN junction of a bipolar junction transistor in the same way that a diode is tested. You can also identify the polarity (NPN or PNP) of an unknown device using this test. In order to do this you will need to be able to identify the emitter, base, and collector leads of the transistor. Refer to a semiconductor data reference manual if you are not sure of the lead identification.

PNP TEST PROCEDURE

1. Connect the meter leads with the polarity, as shown in Fig. 3.2-7 and verify that the base-to-emitter and base-to collector junctions read as a forward biased diode: 0.5 to 0.8 VDC.
2. Reverse the meter connections to the transistor and verify that both PN junctions do not conduct. Meter should indicate an open circuit. (Display = OL.)·
3. Finally read the resistance from emitter to collector and verify an open circuit reading in both directions. (Note: A short can exist from emitter to collector even if the individual PN junctions test properly).

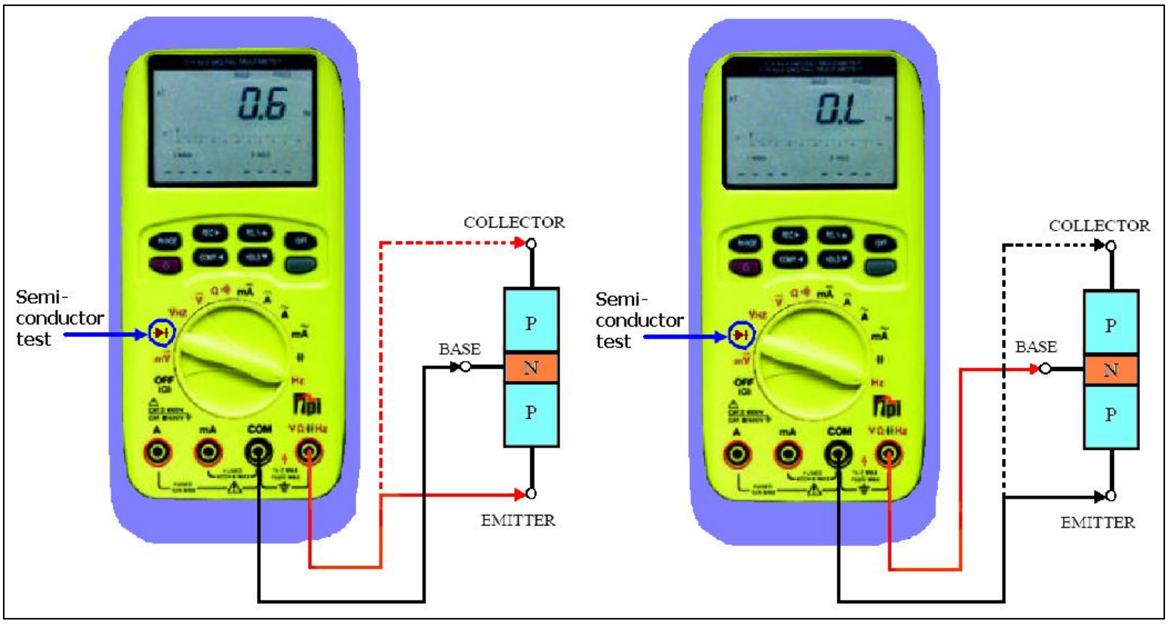


Fig. 3.2-7 PNP Transistor Testing

NPN TEST PROCEDURE

1. Connect the meter leads with the polarity, as shown in Fig. 3.2-8 and verify that the base-to-emitter and base-to collector junctions read as a forward biased diode: 0.5 to 0.8 VDC.
2. Reverse the meter terminals to the transistor and check both PN junctions for (OL) reading.
3. The multi-meter should indicate an open load. (Display = OL.) Finally read the resistance from emitter to collector and verify an open circuit reading in both directions.

NOTE

A short can exist from emitter to collector even if the individual PN junctions test properly.

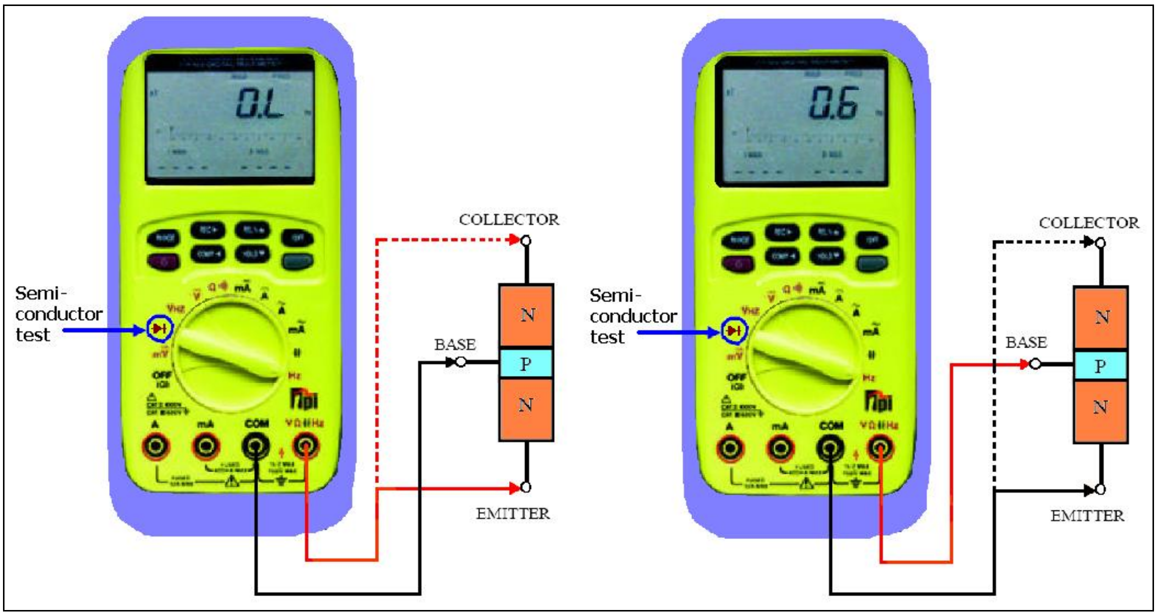


Fig. 3.2-8 NPN Transistor Testing

TRANSISTOR DATA SHEET AND PIN COFIGURATIONS

Fig. 3.2-9 and Fig. 3.2-10 show transistor shapes of Motorola and Mitsubishi-manufacturers, respectively. Because there is a variety of outlines and pin connections, the trainee should always refer to the proper instruction manual or transistor data sheet before making any connections to a transistor.

The data sheet contains the required information and characteristics about the components; such as power consumed, frequency, current, voltage and temperature.

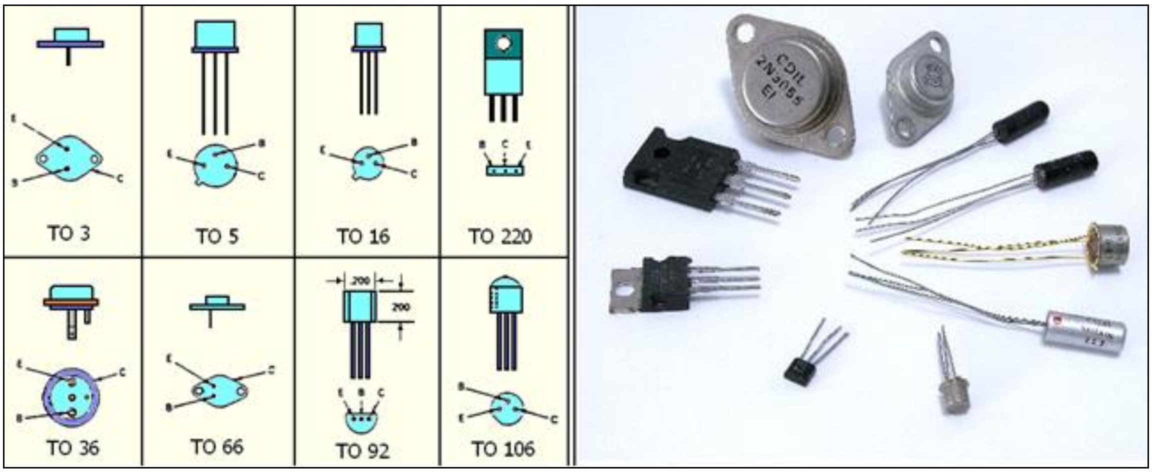


Fig. 3.2-9 Motorola Transistor Package Configurations

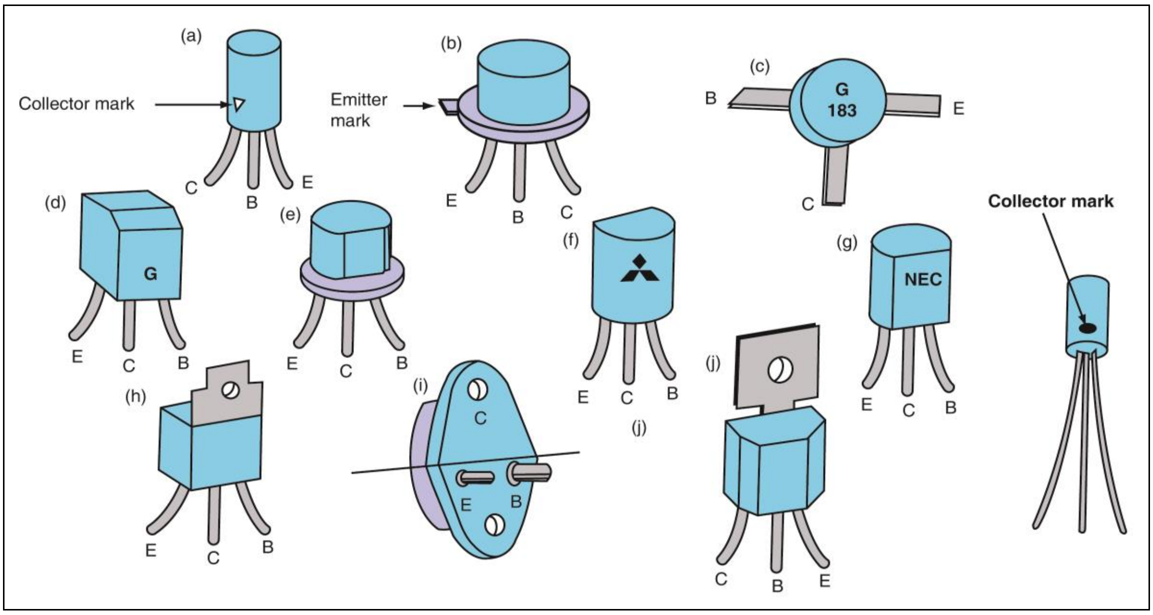


Fig. 3.2-10 Mitsubishi Transistor Package Configurations

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2219		–	60	V
	2N2219A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2219		–	30	V
	2N2219A		–	40	V
I_C	collector current (DC)		–	800	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	800	mW
h_{FE}	DC current gain	$I_C = 10$ mA; $V_{CE} = 10$ V	75	–	
f_T	transition frequency	$I_C = 20$ mA; $V_{CE} = 20$ V; f = 100 MHz			
	2N2219		250	–	MHz
	2N2219A		300	–	MHz
t_{off}	turn-off time	$I_{Con} = 150$ mA; $I_{Bon} = 15$ mA; $I_{Boff} = -15$ mA	–	250	ns

Fig. 3.2-11 Data Sheet of NPN transistor number 2N2219A

SUMMARY

- Bipolar junction transistor has two types: PNP and NPN.
- The collector current I_C is much larger than base current I_B.
- The collector to base current gain β_{DC} is in the range 50 to 200.
- The collector to emitter current gain α_{DC} is in the range 0.5 to 1.
- The transistor can be tested by the multi-meter on the ohmmeter position.
- The transistor is tested by the multi-meter at semiconductor test position.
- The transistor can be biased by base voltage biasing.
- The transistor can be biased by voltage divider biasing resistors.

FORMULAS

Emitter current: $I_E = I_C + I_B$

Collector to emitter current gain: $\alpha_{DC} = I_C / I_E$

Base voltage $V_B = V_E + V_{BE} = V_{BB} - (I_B \times R_B)$

$V_B = V_E + 0.7V$,

Emitter voltage $V_E = I_E \text{ x } R_E$

At voltage divider biasing: $V_B = R_2 \text{ x } V_{CC} / (R_1 + R_2)$

GLOSSARY

Transistor biasing:	Effect with external voltage to the base to let the transistor operate as an amplifier
Current gain:	Multiplying base current by factor to get higher collector current
Voltage divider:	Combination of two series resistor to get fraction of supply voltage
multi-meter:	An instrument to measure current, voltage and resistance
Data sheet:	Component manufacturing information issue to clear its characteristics
OL:	Over Load

REVIEW EXERCISE

1. For the base voltage biasing circuit of Fig. 3.2-12; if β_{DC} = 100. Determine the following:

a. - Base voltage V_B

b. - Collector voltage V_C

c. - Collector to emitter voltage V_{CE}

d. - Base current I_B

e. - Emitter current I_E

f. - Collector current I_C

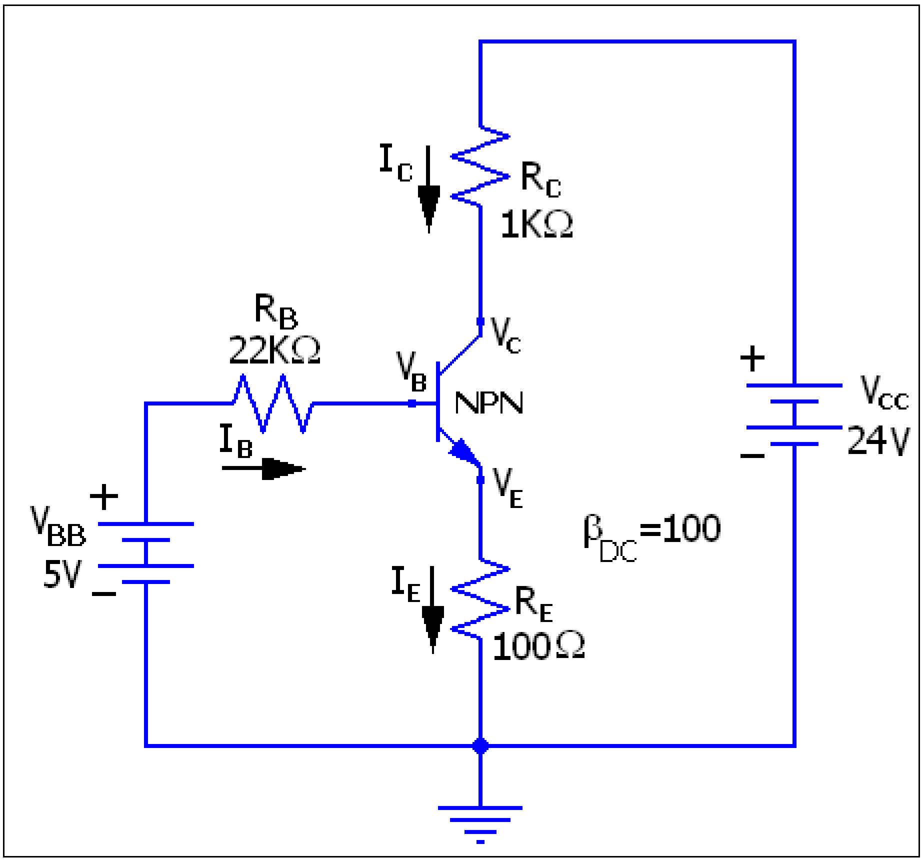


Fig. 3.2-12

2. For the voltage divider biasing circuit of Fig. 3.2-13. Determine each of the following:

a. - Base voltage V_B

b. - Collector voltage V_C

c. - Collector to emitter voltage V_{CE}

d. - Base current I_B

e. - Emitter current I_E

f. - Collector current I_C

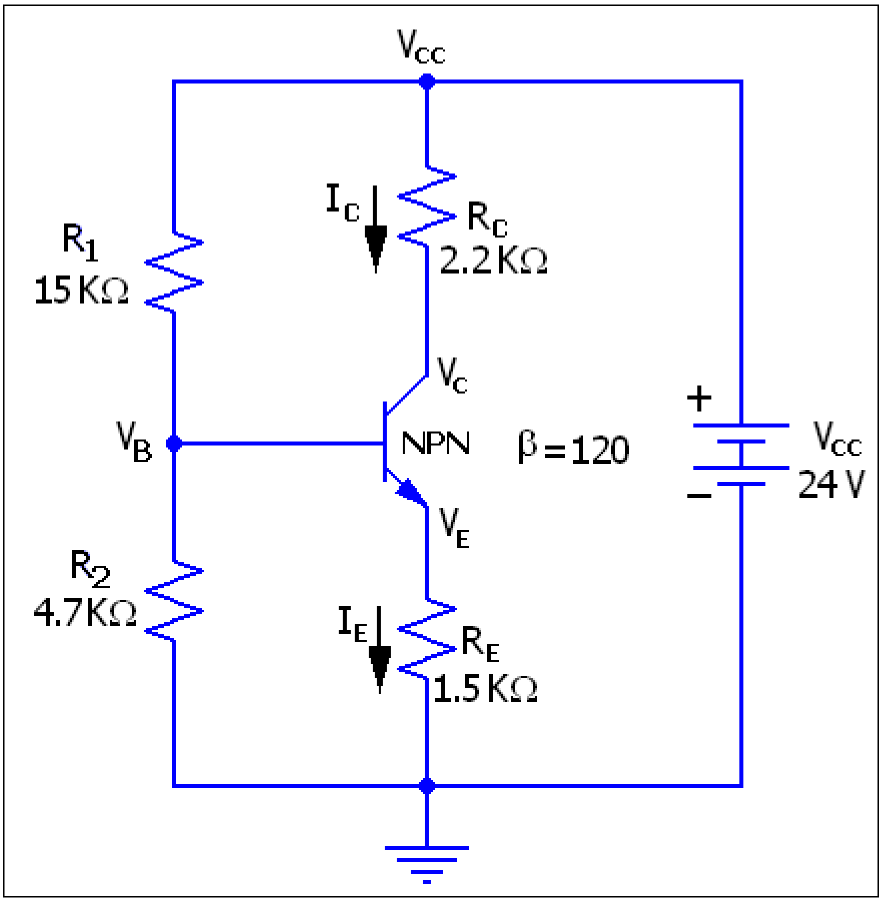


Fig. 3.2-13

TASK 3.2-1
BIPOLAR TRANSISTOR TESTING

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Demonstrate how to test bipolar transistor using digital multi-meter.

TOOLS, EQUIPMENT & MATERIALS

- 1 PNP signal transistor
- 1 NPN signal transistor
- 1 Digital multi-meter

SAFETY PRECATION

Before testing the transistor, transistor terminals must be known as base, collector and emitter. Use the transistor data sheet as a guide to recognize the correct terminals.

PROCEDURE

1. Adjust the multi-meter selector switch at semiconductor test position.
2. Connect the multi-meter red and black leads to the NPN transistor terminals, as shown in Fig. 1-1.
3. Change the multi-meter leads in many positions and record the results in the following table.

Base-Emitter	________________	Collector-Base	________________
Emitter-Base	________________	Collector-Emitter	________________
Base-Collector	________________	Emitter-Collector	________________

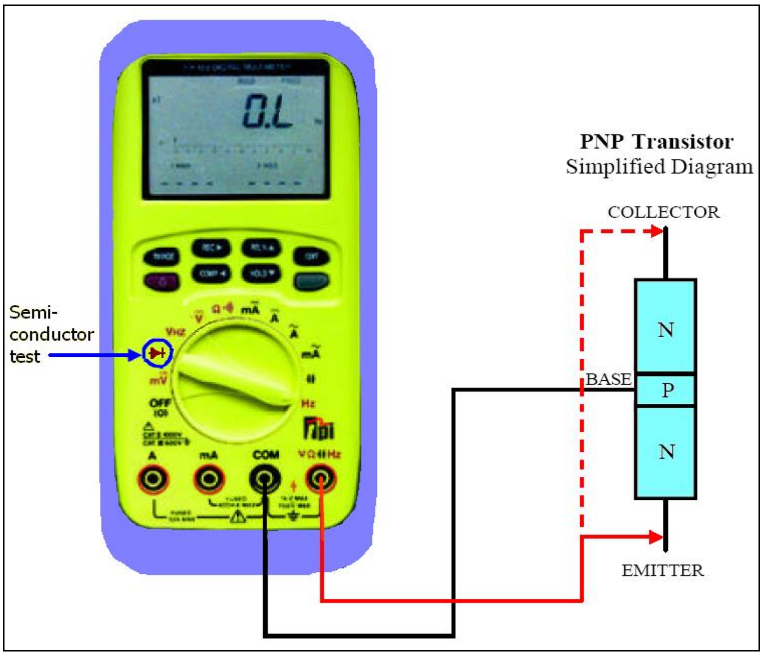
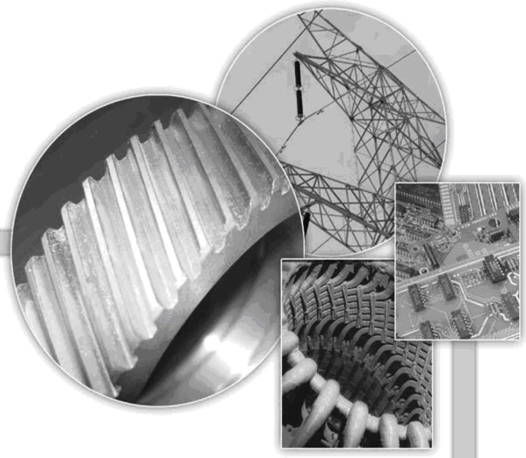


Fig. 1-1 NPN Transistor Testing

4. You should measure two results Base-Emitter & Collector-Emitter of range 0.6 to 0.8V.
5. The other four results have (OL) reading on the multi-meter.
6. Repeat the last steps for PNP transistor, the Emitter-Base & Collector-Base results on the multi-meter screen of the range 0.5 to 0.8V but the four other readings are (OL).



LESSON 3.3

TRANSISTOR OPERATION & APPLICATIONS

LESSON 3.3
TRANSISTOR OPERATION & APPLICATIONS

OVERVIEW

This lesson discusses the transistor biasing conditions. Using transistor in different applications as a switch, amplifier and as a matching device between circuits. Also it discusses the transistor configurations and comparison between them.

OBJECTIVES

Upon completion of this lesson the trainees will be able to:

- Identify the transistor biasing conditions modes.
- Verify the transistor applications as a switch.
- Demonstrate the transistor as an amplifier.
- Use the transistor in matching applications.

Task 3.3-1: Performing for Common Emitter Amplifier Configuration

TRANSISTOR OPERATION

It was discussed in the previous lesson that one purpose of DC bias is to allow a transistor to operate as an amplifier. Thus, a transistor can be used to increase a small AC input signal to a much larger value.

The supply voltage V_{CC} is distributed between R_C, R_E and R_{CE} as shown in Fig. 3.3-1(a).

When:

R_C: represents the resistance between source and collector.

R_E: represents the resistance between emitter and ground.

R_{CE}: represents the transistor variable resistance between collector and emitter.

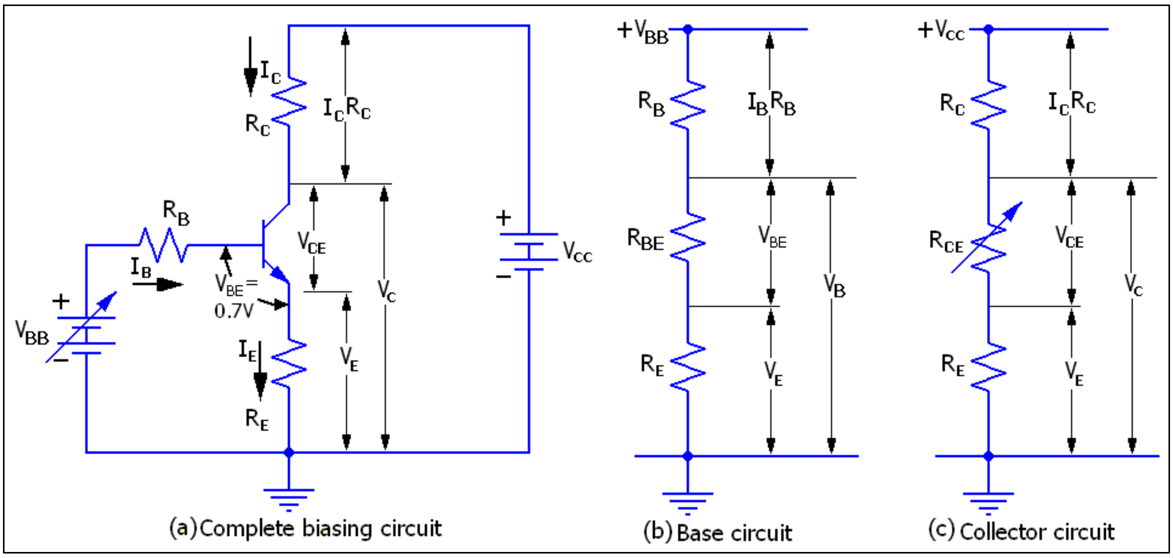


Fig. 3.3-1 (a) Transistor Voltages Distribution at Variable Input Base Signal

When there is no input signal to the base, the collector to emitter resistance R_{CE} is very high thus the collector current is zero and V_{CE} is maximum and equal to V_{CC}. When input signal is applied to the base, R_{CE} is decreased to considerable value and collector current passes resulting in a decrease in V_{CE}.

$$\mathbf{V_{CC} = I_C \times R_C + V_{CE} + V_E}$$

As the input AC base signal varies, the collector to emitter voltage V_{CE} and the Collector current I_C also vary. The transistor characteristic curves for each transistor are known from its manufacture data sheet. When the base signal I_B varies, I_C and V_{CE} are both inversely proportional. Only one curve on the transistor characteristic curves is selected as instantaneous base signal as shown in Fig. 3.3-2 and point Q represents the operating point determining the collector current $I_{C1}$and V_{CE1} for this case.

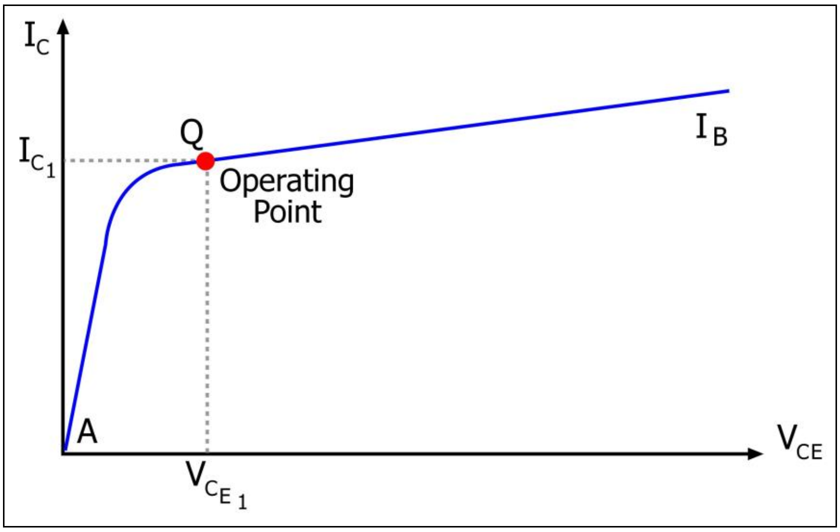


Fig. 3.3-2 Collector Current at one Fixed Value of Base Current

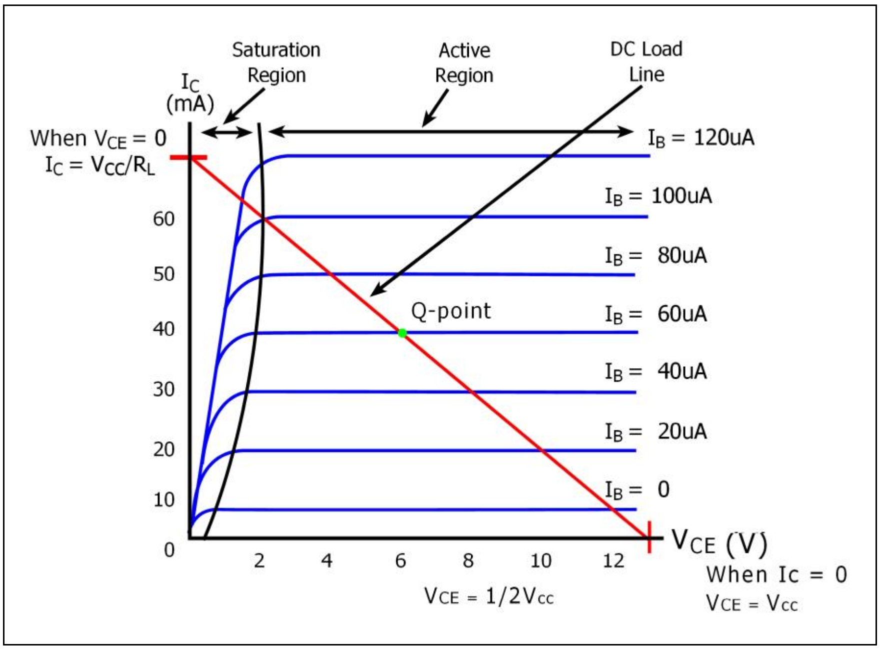


Fig. 3.3-3 Typical NPN Transistor Characteristic Curves

The bipolar transistor characteristic curves are divided into three regions as shown in Fig. 3.3-4. The suitable biasing is done when V_{CE} is half the V_{CC}, so the Q-point is represented somewhere at the center of the load line.

CUT-OFF REGION

It is the bottom area of the curves, where the base current is equal to zero, collector current also equals zero and V_{CE} is maximum; and that means $V_{CE} = V_{CC}$.

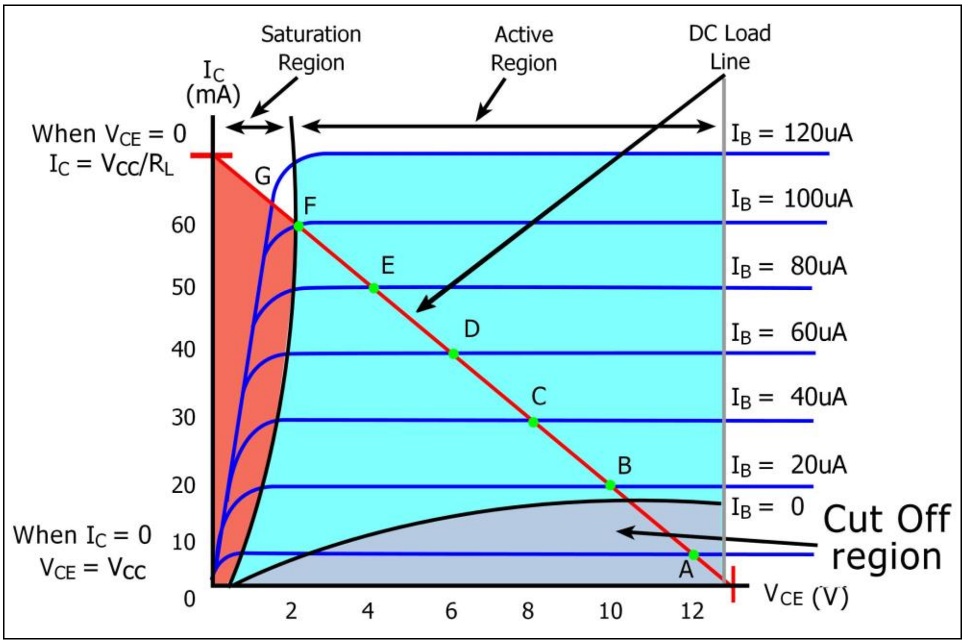


Fig. 3.3-4 Transistor Characteristic Regions

SATURATION REGION

It is on the left upper strip area. This condition exists when the input base signal has its maximum value. The amplified output signal reached its maximum value, so the output cannot be greater than the DC supply ($V_C \leq V_{CC}$).

Saturation and Cut-off modes are exchanging their situations in most applications; especially in the protective relays to produce trip signals as shown in Fig. 3.3-5.

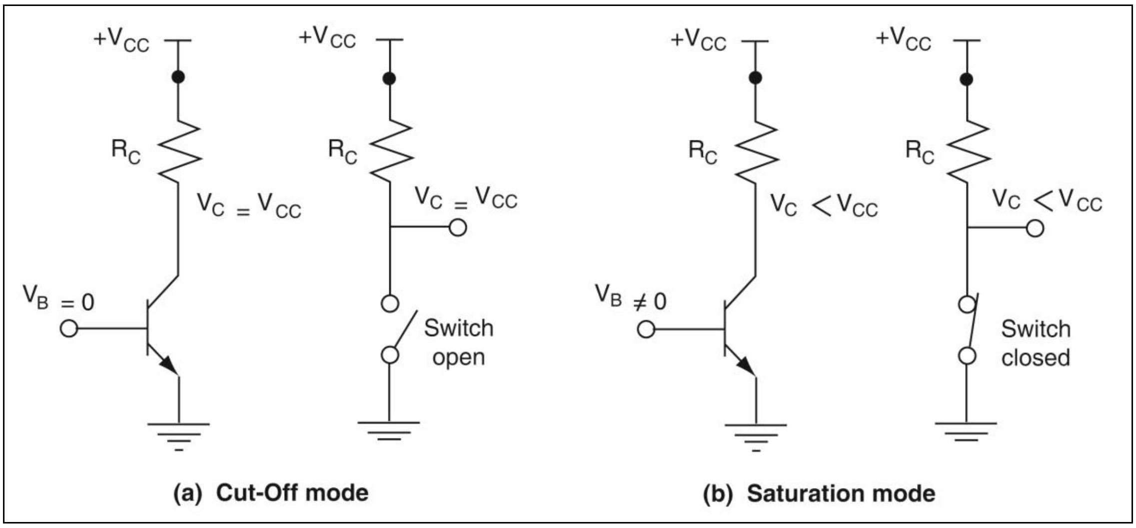


Fig. 3.3-5 Ideal Switching Action of Bipolar Transistor

ACTIVE REGION

It is the major remainder area on the characteristic curves of Fig. 3.3-4; it means the transistor works as an amplifier. These curves provide a family of base curves for a given transistor. Remember that the upper curve often works at saturation mode and the lower curve always works at cut-off mode.

LOAD LINE

Load line is a line that joins between two points on the transistor characteristic curves. One point lies on the horizontal axis at V_{CE} max = V_{CC}. The other point lies on the vertical axis at I_C max at R_{CE} = zero as shown in Fig. 3.3-4.
I_C max = V_{CC} / (R_C + R_E).

The intersection points A, B, C, D, E; F & G represent the operating points at different base currents. From each point you can determine the collector current I_C and collector –emitter voltage V_{CE} at each base current I_B.

EXAMPLE 3.3-1

For the 2N2219A bipolar transistor data sheet characteristic of Fig. 3.3-6, find collector current I_C and V_{CE} if the transistor base current I_B is assumed to be 3mA, when the supply voltage V_{CC} is 30V.

a. What is the collector current gain β_{DC}?

b. If the base current is increased to 5mA, what is the collector current gain?

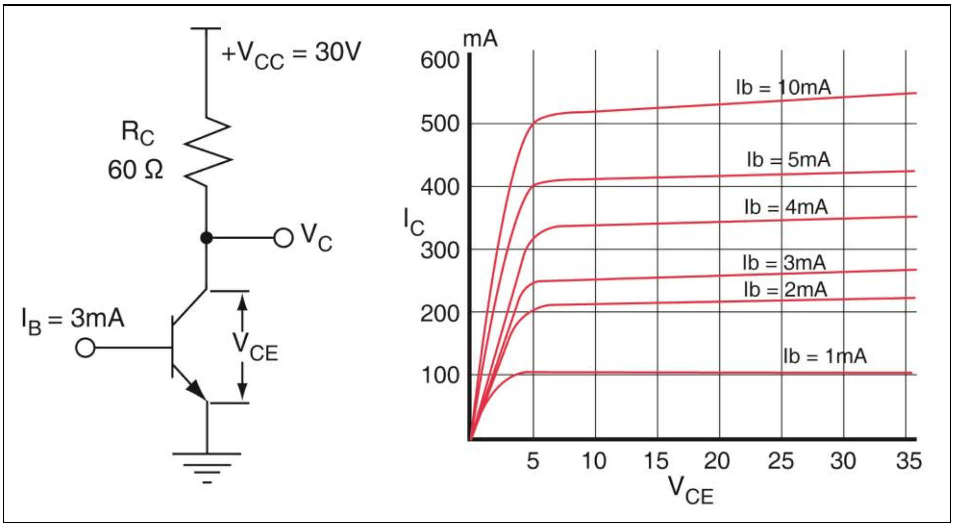


Fig. 3.3-6 Typical Characteristic of Transistor 2N2219A

SOLUTION

First we have to draw the load line on the transistor characteristic curves, mark the 30V of the supply value V_{CC} on the horizontal axis as point A.

Calculate the I_C maximum by assuming $V_{CE} = 0$

So I_C max = V_{CC} / R_C

Then, I_C max = 30 / 60 = 500mA.

Mark this value on the vertical axis as point B, and then join point A and B.

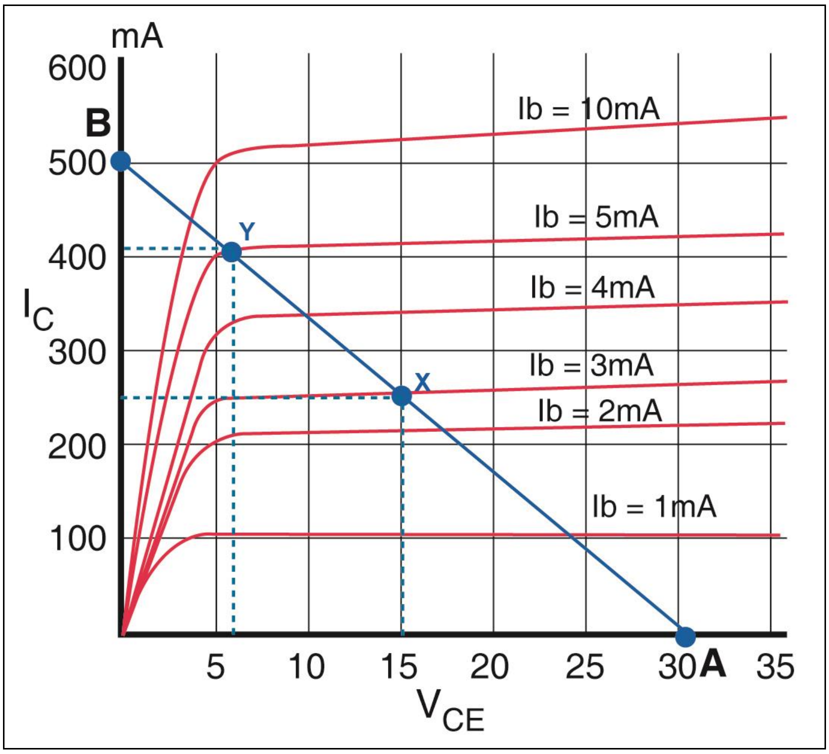


Fig. 3.3-7 Representing Load Line on the Characteristic of the Example

a. Characteristic curves of Fig. 3.3-7, find the point of intersection (X) at the load line for base current curve of 3mA. From this point go horizontally left to find the collector current I_C, finding I_C = 250mA. From point X, go vertically down to find V_{CE} = 15V.

   By applying the collector current gain equation $\beta_{DC} = I_C / I_B$

   Then, $\beta_{DC} = 250 / 3 = 83$

b. On the characteristic curves of Fig. 3.3-7, find the point of intersection (Y) at the load line for base current curve of 5mA. From this point go horizontally left to find the collector current I_C, finding I_C = 410mA. From the same intersection point go vertically down to find V_{CE} = 6.5V. By applying the collector current gain equation $\beta_{DC} = I_C / I_B$. Then, $\beta_{DC} = 410 / 5 = 83$.

   Gain is constant along the load line except for the lower and upper curves.

   The other major curves lay in between represent the active mode of operation of an amplifier where the amplifier gain is stable.

BIPOLAR TRANSISTOR APPLICATIONS

There are four major application areas for the transistor in the protective relays, especially in the static relay.

SWITCHING APPLICATION

It is used to produce a trip signal from the protective relay to initiate the circuit breaker instead of mechanical contacts as shown in Fig. 3.3-8. The output trip signal is produced when the transistor works in saturation mode. When there is no trip signal the transistor works in cut-off mode.

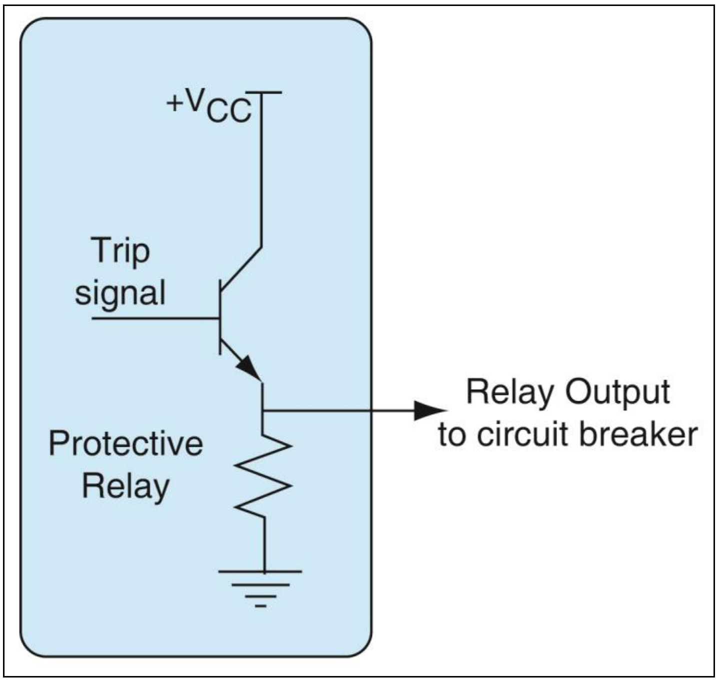


Fig. 3.3-8 Using Bipolar Transistor as a Switch in Protective Relays

AMPLIFIER APPLICATION

There are two major circuit configurations for amplifier applications:

- Common emitter
- Common base

COMMON EMITTER AMPLIFIER CONFIGURATION (CE)

As the name implies, the common emitter amplifier configuration is identified by both input and output signal measured with respect to the emitter as a common terminal as shown in Fig. 3.3-9. This configuration is most popular because both the input current and voltage signals are amplified to make it useful for power amplifier applications.

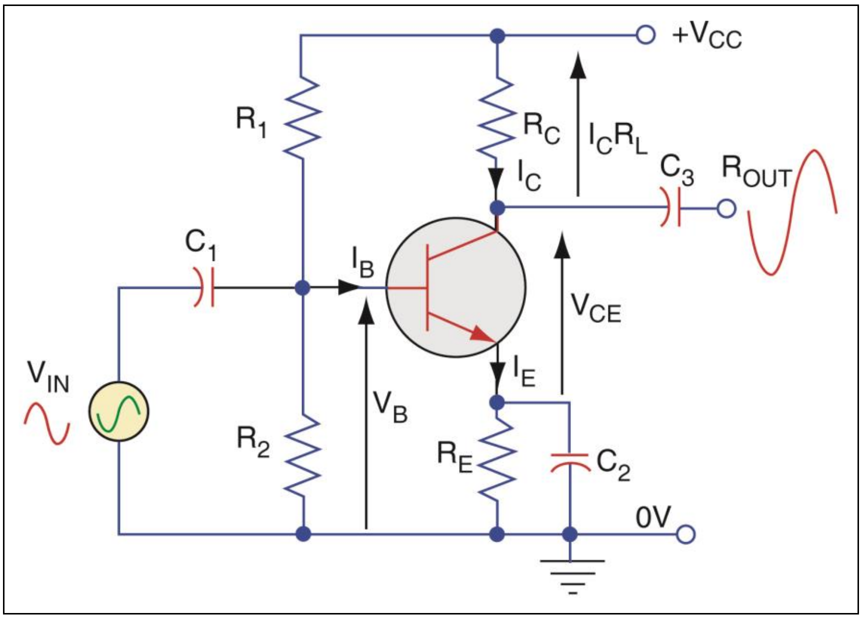


Fig. 3.3-9 Common Emitter Configuration

As shown in Fig. 3.3-9, a single power supply source provides bias voltage for the Base-Emitter junction through the voltage divider resistors R_1 and R_2. Of the two useful transistor circuits used for amplification, the Common Emitter (or grounded emitter) circuit is the most widely used. In the CE circuit, the signal is introduced into the Base-Emitter circuit and output taken from the Collector with respect to ground.
The emitter resistance is usually bypassed by a capacitor (C_2) grounding the AC signals and is common to both the input and output signals. The power supply acts as ground for AC signal at the collector terminal. The transistor input (Base-Emitter circuit) has medium impedance in the order of (1KΩ - 5KΩ). The transistor output impedance (50KΩ - 90KΩ) at Collector-Emitter circuit in parallel with R_C is approximately equal to the value of R_C. The Common Emitter configuration provides high current and voltage gains. The input/output waveforms in Fig. 3.3-9 represent the

input voltage produced by the signal source and the output voltage developed across load resistor R_C. Note that the output of a Common Emitter amplifier is 180° out of phase with respect to the input signal. C_1 and C_3 are coupling capacitors used to pass the signal into and out of the amplifier such that the source or load will not affect the DC bias voltages. C_2 is a bypass capacitor that shorts the emitter signal voltage (AC) to ground without disturbing the DC emitter voltage. Because of the bypass capacitor, the emitter is at signal ground (but not DC ground), thus making the circuit a Common Emitter amplifier. The purpose of the bypass capacitor is to increase the signal voltage gain. The bypass capacitor does have a disadvantage of reducing the input impedance of the CE amplifier.

VOLTAGE GAIN (A_V)

The voltage gain (A_V) for CE amplifier, approximately, is given by:
$A_V = R_C / R_E$ When R_E is not bypassed by C_2

CURRENT GAIN (A_I)

The Current gain in the Common Emitter circuit is obtained from the base and the collector circuit currents. Because a very small change in base current produces a large change in collector current, the AC current gain (A_I or β_{AC}) typically ranges from 50 to 400. The signal current gain of a CE amplifier around a DC operating point is given by: $A_I = \beta_{AC} = I_C\,(ac) / I_B\,(ac)$

Where I_C (ac) = AC signal output current into the load.
I_B (ac) = AC signal input current into the amplifier base.

POWER GAIN (A_P)

The power gain of a CE amplifier is the product of the voltage gain and current gain:
$A_P = A_V \times A_I$

EXAMPLE 3.3-2

For the common emitter Transistor amplifier circuit of Fig. 3.3-10. Determine the base voltage, emitter voltage, emitter current and voltage gain of the amplifier, When R_E is un-bypassed (without C_3).

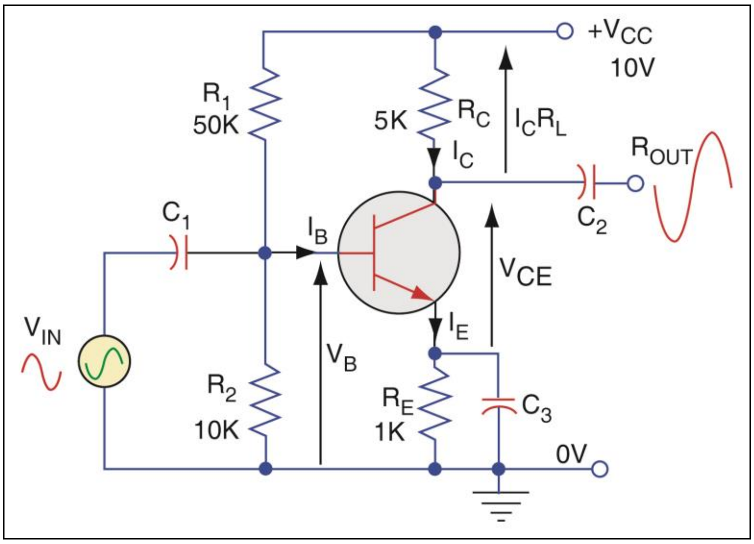


Fig. 3.3-10 Common Emitter Example Circuit

SOLUTION

$V_B = V_{CC} \text{ x } R_2 / (R_1 + R_2) = 10V \text{ x } 10K / (50K + 10K) = 1.67V$

$V_E = V_B - V_{BE} = 1.67 - 0.7 = 0.97V$, $I_E = V_E / R_E = 0.97 / 1K = 0.97 \text{ mA}$

Voltage gain $A_V = R_C / R_E = 5 / 1 = 5$ (without C_3)

EXAMPLE 3.3-3

a. For the transistor switching circuit in Fig. 3.3-11, what is V_{CE} when $V_{IN} = 0$ V?

b. What minimum value of I_B is required to saturate this transistor, if the $\beta_{DC} = 200$?

c. Calculate the maximum value of R_B when $V_{IN} = 5V$.

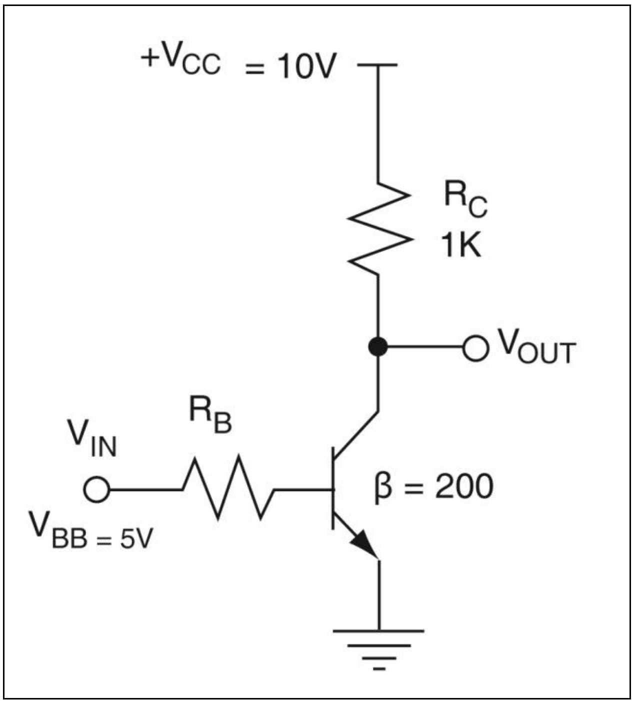


Fig. 3.3-11 Transistor Switching Example

SOLUTION

a. When V_{IN} = 0V, $I_B = I_C$ = 0A $\quad V_{CE} = V_{CC}$ = 10V

b. Saturation occurs when V_{CE} = 0.

Then, I_C sat. = V_{CC} / R_C = 10V / 1K = 10mA

The minimum value of I_B occurs at maximum value of I_C (at saturation).

When $\beta_{DC} = I_C / I_B$

Then, I_B (min) = 10 mA / 200 = 50μA

c. From the base-emitter circuit, the voltage across R_B is equal to ($V_B - V_{BE}$)

= 5V – 0.7V= 4.3V

By applying Ohm's low, R_B = 4.3V / 50μA = 86KΩ

COMMON BASE AMPLIFIER CONFIGURATION (CB)

In this configuration, the current gain is less than unity and the voltage gain is higher than that of the common emitter configuration gain. This configuration has the lowest input impedance and the highest output impedance of the two configurations mentioned in this lesson. It has few applications because there is no advantage at low and medium frequencies of the common base configuration.

The common base configuration is as shown in Fig. 3.3-12. The main advantage of the common base configuration is that it has a better performance at high frequencies.

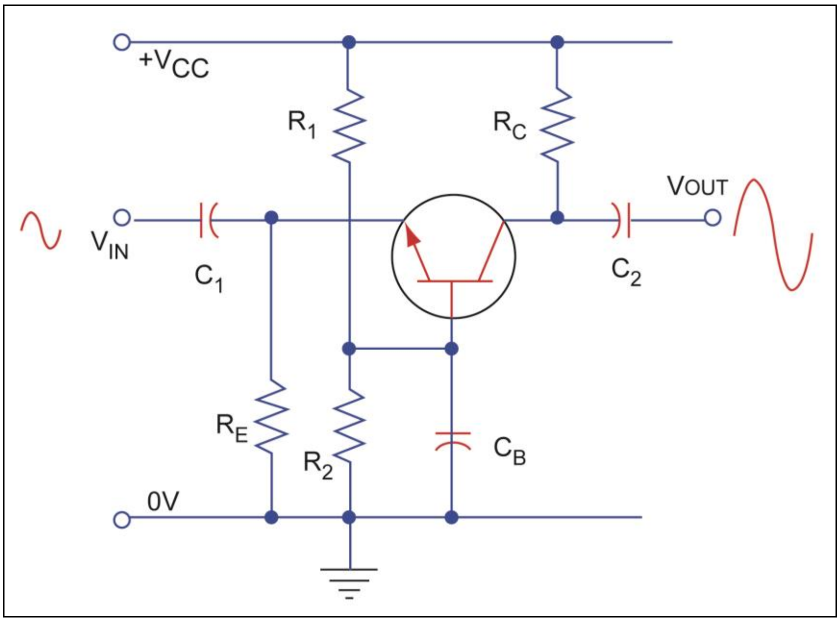


Fig. 3.3-12 Common Base Amplifier Configuration

MATCHING APPLICATION

It is the joining between amplifier stages or between devices without signal distortion

MATCHING CONDITIONS

In order to transfer an output signal of device A to apply a certain process in device B, the signal is passing through the source signal, R_{OUT} of device A and R_{IN} of device B.

The output resistance R_{OUT} must be very low and input resistance R_{IN} must be very high as shown in Fig. 3.3-13.

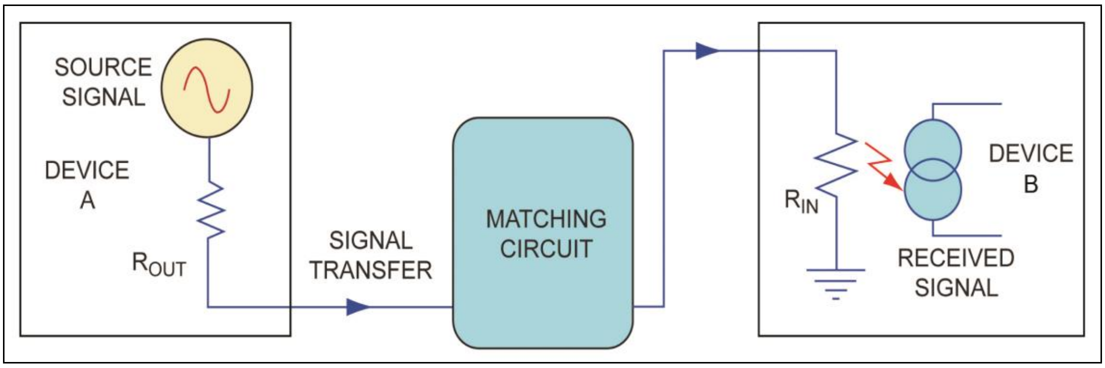


Fig. 3.3-13 Matching Circuit between Two Devices

INPUT RESISTANCE

The input resistance is the resistance seen by the current source or voltage source that drives the signal circuit.

OUTPUT RESISTANCE

The output resistance is an indication of a source's ability to drive load impedance. An ideal voltage source has zero output resistance, and an ideal current source has infinite output resistance.

In most cases both of R_{OUT} and R_{IN} are found unreliable for those conditions and result in a distortion and weakness for the transferred signal. The solution for this problem is to use matching circuit as shown in Fig. 3.3-13.

COMMON COLLECTOR AMPLIFIER CONFIGURATION (CC)

In this configuration, the current gain is higher than that of the common emitter configuration and the voltage gain is less than unity. The input impedance is the highest and the output impedance is the lower of the two configurations mentioned

above. It is also called emitter follower and has wide applications as a match or buffer between amplifier stages. In this configuration emitter is sharing between base and collector circuits.

In this configuration, the current gain is higher than that of the common emitter configuration and the voltage gain is less than unity. The input impedance is the highest and the output impedance is the lower of the two configurations mentioned above. It is also called emitter follower and has wide applications as a match or buffer between amplifier stages. In this configuration emitter is sharing between base and collector circuits.

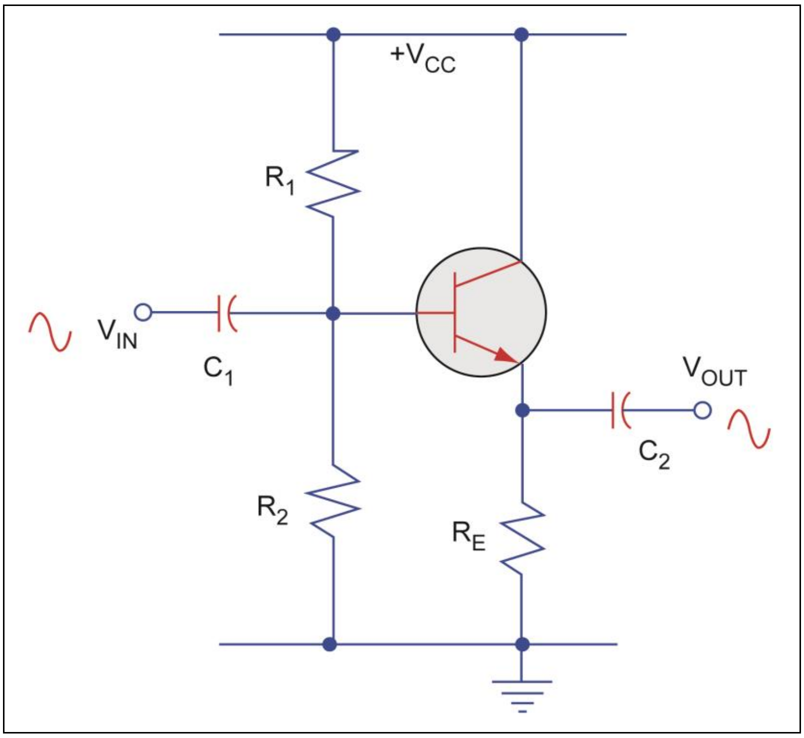


Fig. 3.3-14 Common Collector Amplifier Configuration

The following table shows a comparison between the three types of transistor configuration.

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	HIGH	MEDIUM	LOW
CURRENT GAIN POWER GAIN	LOW (α) LOW	MEDIUM (β) HIGH	HIGH (γ) MEDIUM
INPUT RESISTANCE OUTPUT RESISTANCE	LOW HIGH	MEDIUM MEDIUM	HIGH LOW

Table 3.3-1 Transistor configuration comparison chart

SUMMARY

- The bipolar transistor operating characteristic has three modes.
- Saturation and Cut-off operation modes are used in most switching applications.
- Saturation mode means that output signal reached its maximum value.
- In the common emitter transistor configuration, the input base signal and output collector signal are 180^o shift.
- The load line represents all the expected operating points of the transistor.
- Each transistor has its characteristic curves, parameters and its industrial number.
- The transistor resistance between collector and emitter R_{CE} is variable during active mode.
- The input series capacitor C_1 is used to prevent DC biasing from backing to the input signal source V_{IN}.
- The series capacitor C_2 which is used to filter the output signal from the DC biasing.
- In saturation mode the transistor looks like a closed switch.
- The collector current gain of small signal amplifier β_{AC} is different from β_{DC}.

- Gain is a ratio of output divided by input, therefore, it has no units but is given the symbol (A) with the most common types being, Voltage Gain (A_V), Current Gain (A_I) and Power Gain (A_P).
- The Common Emitter Amplifier configuration is the most common form of all the general purpose voltage amplifier circuits.
- Common base amplifier is more suitable for high voltage gain but high output resistance.
- Common collector is more suitable for matching operation between cascaded amplifier stages.

FORMULAS

$V_{CC} = I_C \times R_C + V_{CE} + V_E$

Where: V_{CC}: the supply voltage $\quad$ I_C: collector current

R_C: collector resistance $\quad$ V_{CE}: voltage between collector and emitter

V_E: emitter voltage

At saturation: $V_{CE} = 0V$ $\quad$ At cut-off $V_{CE} = V_{CC}$

To represent load line, $\quad$ $I_C \max = V_{CC} / (R_C + R_E)$ and $V_C = V_{CC}$

For small signal amplifier, $\quad$ $\beta_{AC} = I_C / I_B$

The measured voltage gain A_V of the amplifier:

$$\mathbf{A_V = \frac{Vout}{Vin}} \quad \text{Or} \quad \mathbf{A_V \approx \frac{R_C}{R_E}}$$

Where: V_{OUT} = voltage signal at the collector

V_{IN} = voltage signal at the base

Power gain (A_P)

$A_P = A_V \times A_I$

Where: A_V = Voltage gain $\quad$ A_I = Current gain

GLOSSARY

Cut-off mode	The transistor has no input signal
Load line	Operating line to determine operating points
Saturation mode	The output signal equal to the supply voltage
Filter capacitor	Separate AC signal from DC signal
Voltage gain	The ratio between output signal and input signal
Active region	The output signal has intermediate value with the supply
Common emitter	The emitter terminal is common to input and output
Input resistance	The receiving element resistance of the amplifier
Output resistance	All the circuit resistance without load
Power gain	Percentage amount of power amplification
Matching	Joining between multiple circuits
Cascading	Multiple circuits in series with output of proceeding stage acts as input to the next stage

REVIEW EXERCISE

Choose for correct answer:

1. For the cut-off region, its location on the characteristic curves:
   a. - In the middle of the curves. b. - In the bottom of the curves.
   c. - In the upper right of the curves. d. - In the upper left of the curves.

2. The saturation region, its location on the characteristic curves:
   a. - In the middle of the curves. b. - In the bottom of the curves.
   c. - In the upper right of the curves. d. - In the upper left of the curves.

3. The transistor at cut-off mode is represented with:
   a. - Closed switch. b. - Opened switch.

4. The transistor at saturation mode is representing with:
   a. - Closed switch. b. - Opened switch.

5. The most suitable mode for power amplifier applications is:
   a. - Common base. b. - Common emitter.
   c. - Common collector. d. - Any configuration.

6. The most suitable mode for matching between cascaded amplifiers is:
   a. - Common base. b. - Common emitter.
   c. - Common collector. d. - Any configuration.

7. Good matching between devices is occurred when:
   a. - Low input & high output resistance. b. - High input & low output resistance.
   c. - Low input & low output resistance d. - High input & high output resistance.

8. The output capacitor of the common emitter amplifier is used to:
   a. - Fix the amplified output signal. b. - Smooth the amplified output signal.
   c. - Regulate the amplified output signal. d. - Filter the amplified output signal.

9. For the transistor switching circuit of Fig. 3.3-16,

   a. Calculate V_{CE} when $V_{IN} = 0$ V?

   b. What minimum value of I_B is required to saturate this transistor, if $\beta_{DC} = 120$?

   c. Calculate the maximum value of R_B when $V_{IN} = 2.5$V.

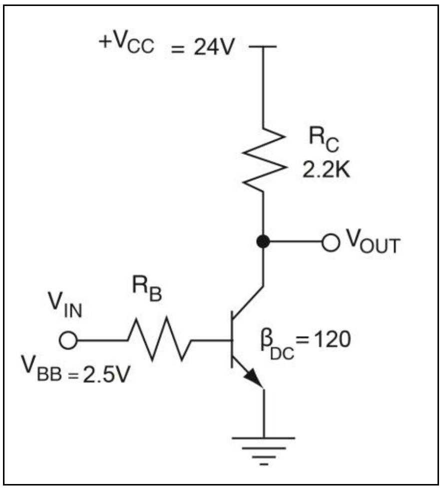


Fig. 3.3-16 Transistor Switching Circuit

10. For the 2N2222A bipolar transistor data sheet characteristic of Fig. 3.3-15, find collector current I_C and V_{CE} if the transistor base current I_B is assumed to be 200µA, when the supply voltage V_{CC} is 18V.

    a. Calculate the collector current gain β?

    b. If the base current is increased to 400µA, calculate collector current gain?

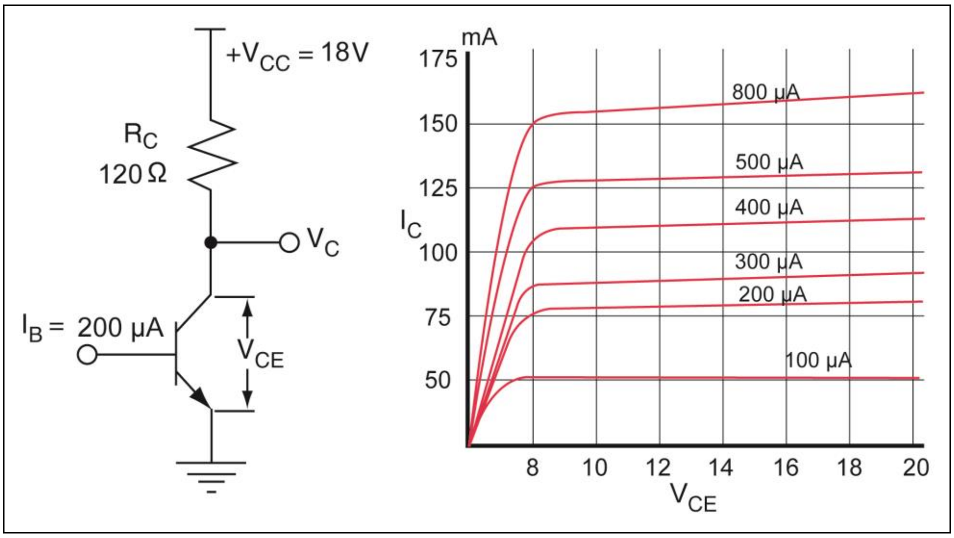


Fig. 3.3-15 Typical Characteristic of Transistor 2N2222A

TASK 3.3-1
COMMON EMITTER AMPLIFIER

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Demonstrate the common emitter amplifier circuit.
- Determine the circuit parameters.
- Measure the waveforms and compare it with the calculated values.

TOOLS, EQUIPMENT & MATERIALS

- 1 Analog Electronic Trainer (ETW-3600)
- 1 Digital multi-meter
- 1 Dual Trace Oscilloscope
- 1 NPN transistor (417-801)
- 1 470 Ω resistor
- 1 14.7 KΩ resistor
- 1 110 KΩ , 100 KΩ resistor
- 1 100 KΩ potentiometer (on Trainer)
- 1 110 µF electrolytic capacitor
- 1 1100 µF electrolytic capacitor

PROCEDURE

1. Plug in the Trainer, making sure that it is turned off at this time. Connect the circuit shown in Fig. 1-1 as per layout diagram for the circuit in Fig. 1-2, ensuring + lead of capacitor C_3 (100µF) not connected to the emitter terminal (un-bypassed capacitor).

NOTE

Do not operate the AC supply at this time.

Check the transistor terminals carefully during the circuit connection.

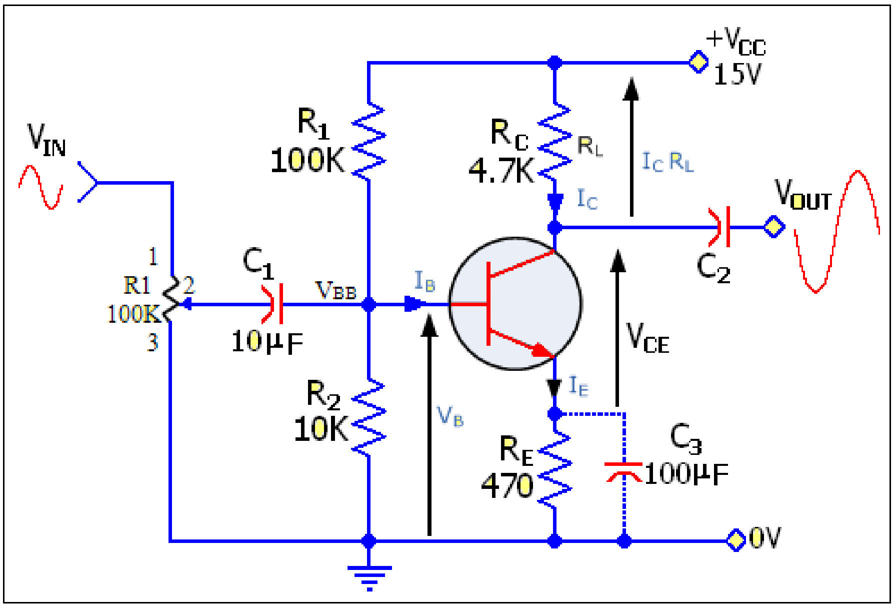


Fig. 1-1 AC Coupled CE Transistor Amplifier

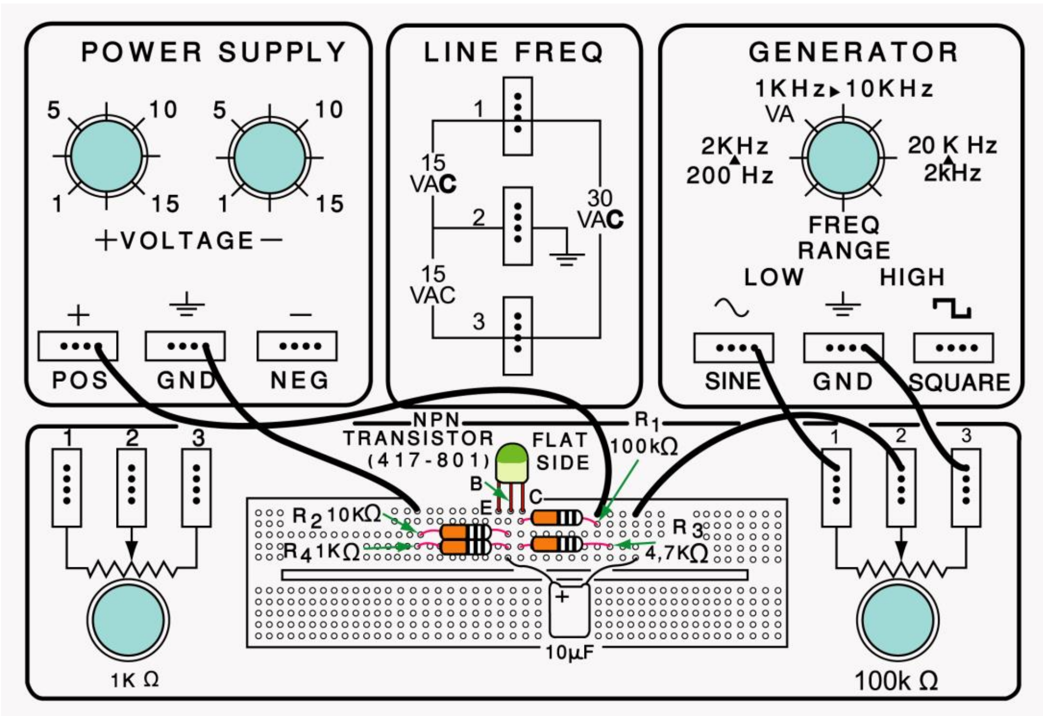


Fig. 1-2 Layout Diagram for CE Transistor Amplifier

2. From the voltage divider R_1 & R_2, determine the base voltage V_{BB}.
3. $V_{BB} = R_2 \text{ x } V_{CC} / (R_1 + R_2) = 10K \text{ x } 15V / (1100K + 10K) = 1.$
4. Determine emitter voltage. $V_E = V_{BB} – V_{BE} = 1.36 – 0.7 = 0.66V$
5. Determine the voltage gain. $A_V = R_C / R_E = 4.7K / 470 =$ _____________
6. Use the digital multi-meter, set the negative lead on the circuit ground and measure the voltage on each of base and emitter then record the result.

   V_B = ______________ **V_E =** ______________
7. Compare the measured values of V_B & B_E with the calculated values.
8. Operate the AC signal and adjust the potentiometer knob to measure base signal VB of 0.5VP-P on the oscilloscope on CH1.

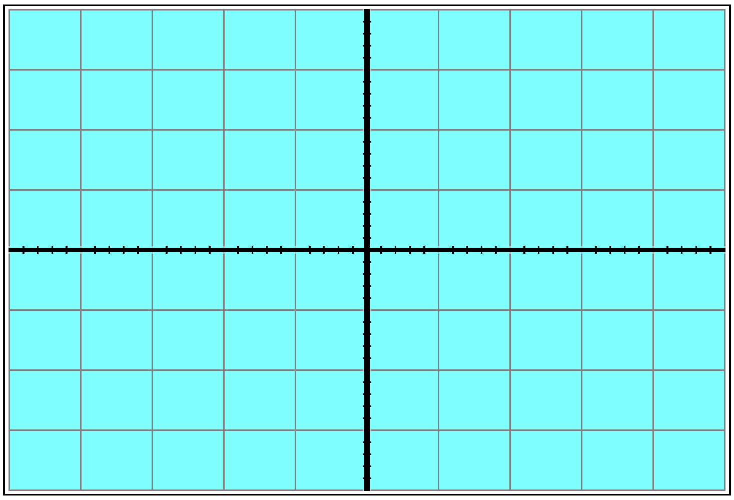
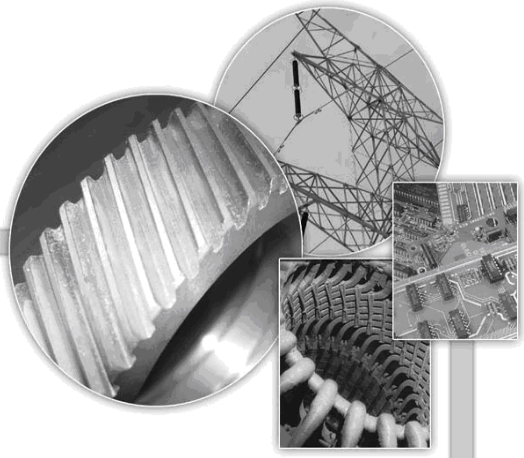


Fig. 1-3 Plotting Signal Waveforms

9. Set the probe of CH2 of the oscilloscope on the collector terminal and measure the output signal.
10. Adjust the oscilloscope to show the input and output signals on CH1 & CH2 respectively.
11. Measure the output signal waveform and compare it with the input signal.

    You should find the output signal $10V_{P-P,}$ reversed phase as compared to input signal.
12. Divide the output signal by the input signal to determine the voltage gain A_V.
13. You should find $A_V = V_{OUT} / V_{IN} = 5 / 0.5 =$ _____________



LESSON 3.4

WAVE SHAPING CIRCUITS & OSCILLATORS

LESSON 5.4
WAVE SHAPING CIRCUITS & OSCILLATORS

OVERVIEW

This lesson familiarizes the participants with different types of wave shaping circuits and oscillators.

OBJECTIVES

Upon completion of this lesson, the participants should be able to:

- Describe wave clipping using schematics.
- Describe wave clamping using schematics.
- Describe AC coupling.
- Describe differentiator and integrator actions using schematics.
- Draw Schmitt trigger circuit and explain operation.
- Explain multi-vibrator types and their modes of operation.
- Understand the operation of an oscillator as an amplifier with positive feedback.
- Describe an oscillator as made up of a frequency-determining network and an amplitude stabilizing system.
- Understand the function of an oscillator and its application.
- Understand function of crystal oscillators and characteristics of crystals.
- Understand operation of hartley and colpitts crystal oscillators.

Task 3.4-1 Driven Rectangular-Wave Shaping Circuits

Task 3.4-2 Verify Operations of Oscillators

WAVE SHAPING CIRCUITS

CLIPPING

In electronics, a clipper is a device designed to prevent the output of a circuit from exceeding a predetermined voltage level without distorting the remaining part of the applied waveform. A clipping circuit consists of linear elements like resistors and non-linear elements like junction diodes or transistors, but it does not contain energy-storage elements like capacitors. Clipping circuits are used to select the part of a signal wave form, which lies above or below a certain reference voltage level. Thus a clipper circuit can remove certain portions of an arbitrary waveform near the positive or negative peaks. Clipping may be achieved either at one level or two levels. Usually under the section of clipping, there is a change brought about in the wave shape of the signal.

The process of flattening one or both peaks of an AC waveform is known as clipping or limiting. A large degree of clipping as seen in Fig. 3.4-1 can produce a clipping wave from a sine wave input.

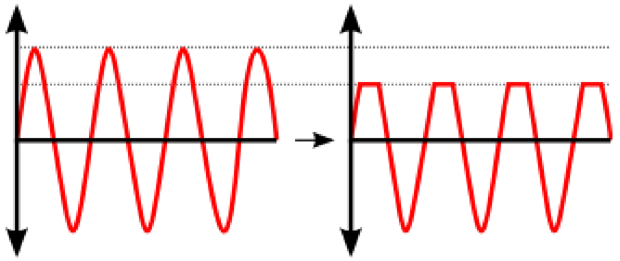


Fig. 3.4-1 Clipping Waveform

Fig. 3.4-2 shows the circuits that produce waves shown in Fig. 3.4-1. For example, in Fig. 3.4-2, two biased diodes are used. The cathode of D1 is held at +5 volts. When the input swings above +5.7 volts, D_1 conducts, clipping the output. The anode of D_2 is held at –5 volts. When the input swings below –5.7 volts, D_2 conducts clipping the output to this level. When the input is below +5.7 volts, but above 5.7 volts, neither diode conducts and the input signal is coupled to the output. Zener diodes can be used to perform the same idea.

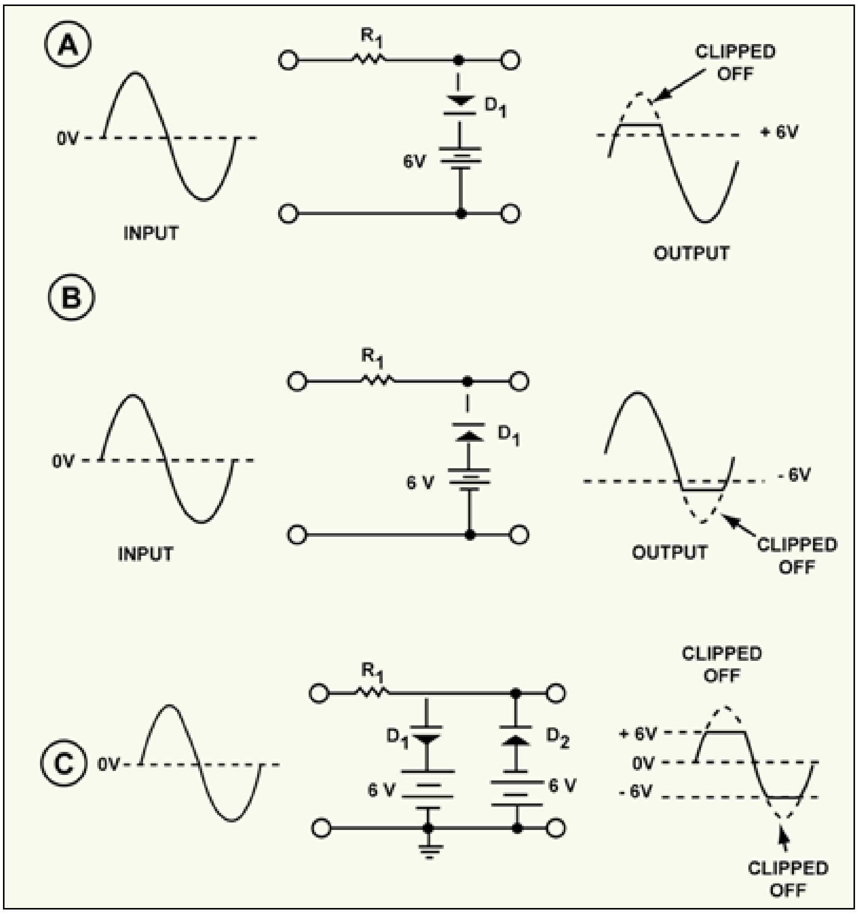


Fig. 3.4-2 Example

CLAMPERS

A clamping circuit is used to change the DC reference voltage of a waveform. It clamps the top or bottom of a waveform to a DC voltage. Unlike the clipper, the clamping circuit does not change the shape (distort) of the waveform, it simply inserts a DC reference voltage. For this reason, the clamper is sometimes called a DC restorer, Fig. 3.4-3. Unlike the clipper circuit the clamper passes all of the input waveform, but offset to a new reference.

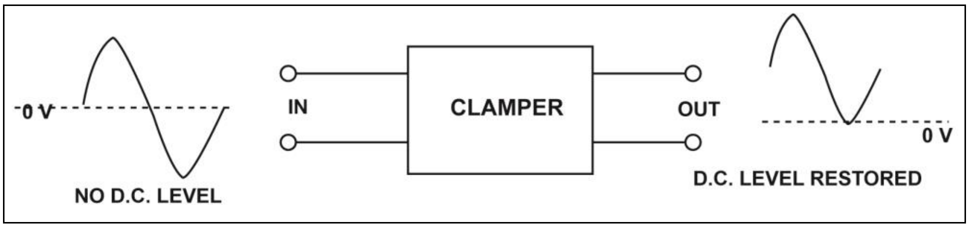


Fig. 3.4-3 a Clamping Block Diagram

A simple diode clamping circuit is shown in Fig. 3.4-4 (a). In this example, a square wave Fig. 3.4-4 (b) is used as the input signal. The purpose of this circuit is to clamp the top of the square wave to 0 volts, without changing the shape of the waveform.

Notice that the capacitor has unequal charge and discharge paths. When the input swings positive, C_1 can quickly charge through D_1. The charge path is shown by the solid arrow. However, when the input swings negative, D_1 cuts off and C_1 must discharge through the fixed resistance of R_1 as shown by the dotted arrow. The time constant for charging C_1 is extremely short because of the low resistance of the conducting diode. By contrast, the discharge time constant is quite long because R_1 has a large value of resistance. The net result is that after a few cycles, C_1 will be charged to the peak of the positive half cycle (+10 V). C_1 discharges very little between the positive pulses because of the long discharge time constant of R_1 and C_1.

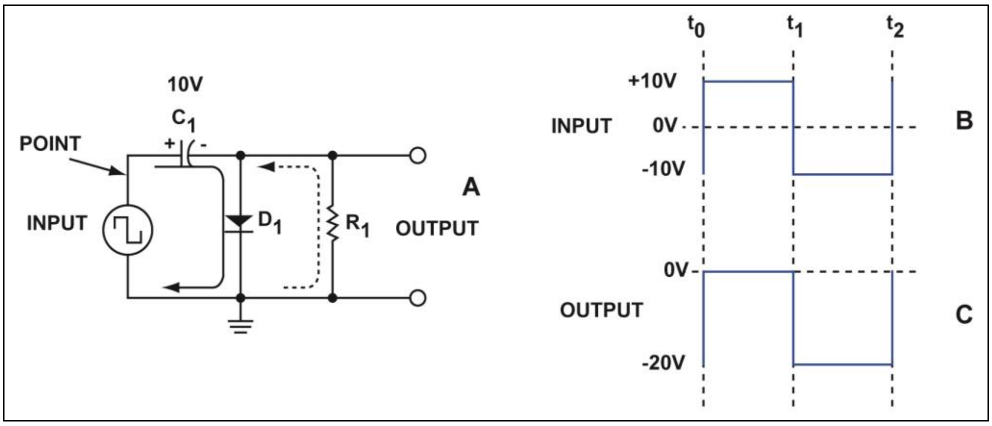


Fig. 3.4-4 Simple Diode Clamping Circuit

With C_1 charged to +10 volts, let's determine the appearance of the output waveform:

At time t_o, point A is +10 volts with respect to ground; also, A is at +10 volts with respect to the right plate of C_1. Therefore, the right plate is at 0 volts with respect to ground from time t_0 to time t_1. That is, the output is 0 volts from time t_o time t_1.

Note that: the input varies from –10 volts to +10 volts.

At time t_1, the input swings negative. Point A goes to –10 volts with respect to ground. Again, the right plate of C_1 is at –10 volts with respect to point A. Therefore, the output voltage is:

(–10V) + (–10V) = –20 V

The output remains at –20 V from time t_1 to time t_2. As you see in Fig. 3.4-4 (c), the shape of the waveform is still a square wave, but the 0 volt reference has been shifted to the top of the waveform. The output of the clamper varies from 0 volts to –20 V. That is, the top of the waveform has been clamped to 0 volts. This is called positive peak clamping. The positive peak has been clamped.

AC COUPLING

The reverse of the DC restorer is the AC coupler, which removes the DC level from the input, Fig. 3.4-5. The AC coupler is usually as simple as a single capacitor blocking the DC while allowing the AC to go through.

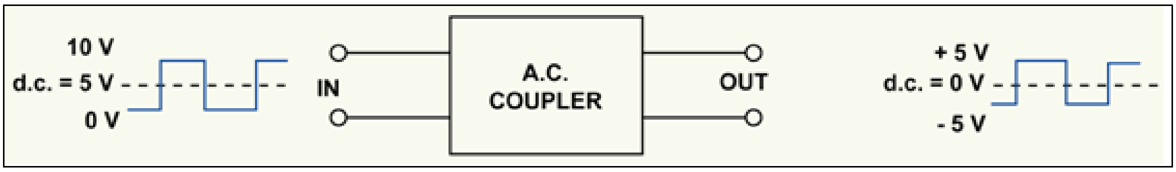


Fig. 3.4-5 AC coupling

THE DIFFERENTIATOR

The Differentiator is a high pass filter which, when fed with a square wave reproduces the high frequency components only, namely the fast rising and falling edges in the form of positive and negative going spikes. The output waveform is as shown in Fig. 3.4-6 and is sometimes known as short duration pulses. Each cycle of the input wave produces two spikes at the output with amplitude equal to that of the input.

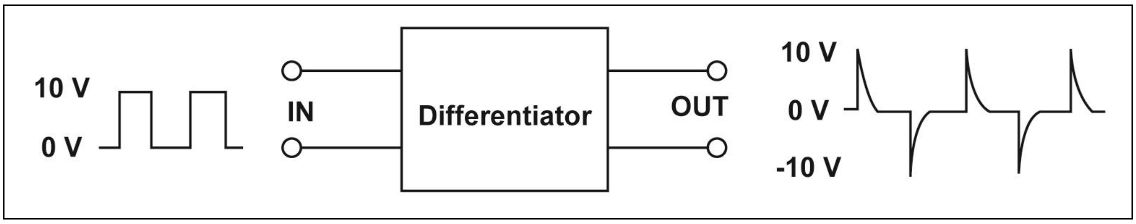


Fig. 3.4-6 Differentiator

The input and output sine waves are shown in parts B and C as shown in Fig. 3.4-7. The differentiator cannot change the shape of a pure sine wave. It can change the amplitude and shift the phase, but it cannot distort a sine wave.

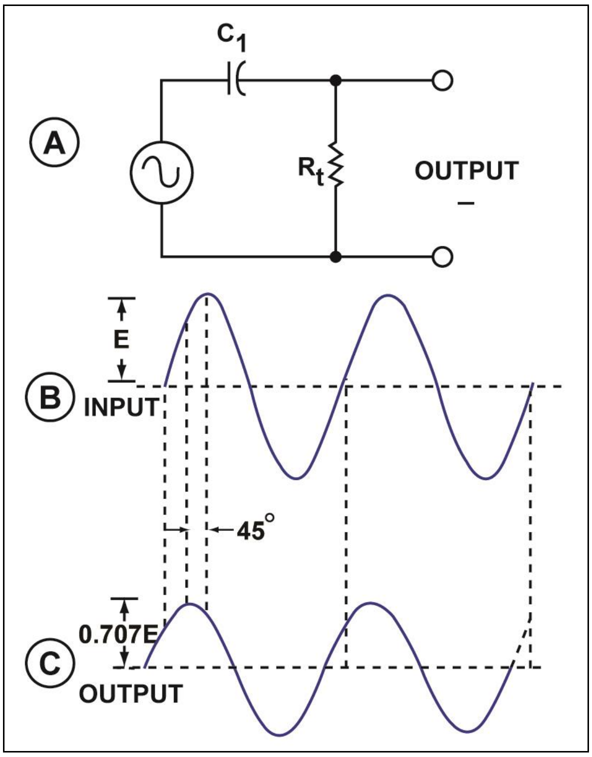


Fig. 3.4-7 Input and Output Waveforms with a Sine Wave Applied

Fig. 3.4-8(a) shows the same circuit with a square wave applied. Fig. 3.4-8(b) & 3.4-8(c) show the input and output waveforms. At time t_o, the input square wave suddenly jumps positive. C_1 sees this almost instantaneous change as a very high frequency. Therefore, the X_C of the capacitor is quite low compared to R at this instant. In other words, at this first instant, C_1 acts almost like a short. Consequently, the full increase in voltage is developed across R_1 at time t_o. The output voltage immediately jumps to a high positive value. The capacitor immediately begins to charge to the applied positive voltage, as shown by the solid arrow. The charge of C_1 is controlled by the RC time constant. As C_1 charges, it forces current through R_1, developing a positive voltage at the output. However, the current through R_1 quickly decreases as the capacitor becomes charged. In fact, when C_1 is fully charged, the current through R_1 ceases altogether. Thus, the output voltage quickly decreases, falling back to 0 volts

when C_1 is completely charged at time t_1. The output voltage remains at 0 volts until time t_2. The differentiator will produce the results shown in Fig. 3.4-8(c) only if the RC time constant is short when compared to the period of the input square wave. At time t_2, the input voltage suddenly returns to 0 volts. C_1 immediately begins its discharge through R_1 as shown by the dotted arrow.

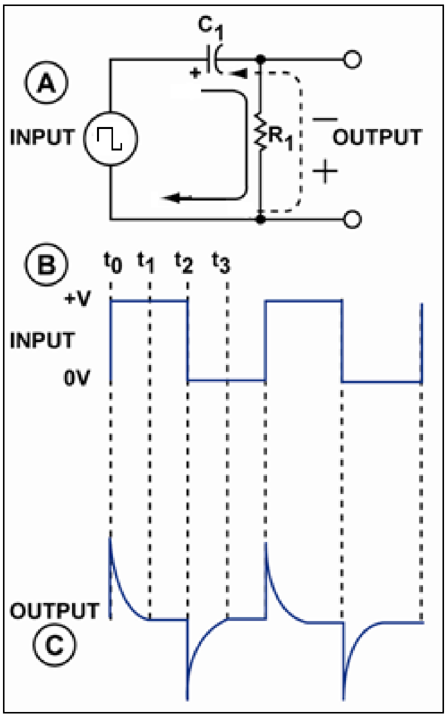


Fig. 3.4-8 Differentiator Changes A Square Wave To Spikes

This develops a negative voltage across R_1. Thus, the output suddenly goes sharply negative as shown in Fig. 3.4-8 (c). As C_1 discharges, the current through R_1 quickly decreases. The output voltage returns to 0 volts at time t_3 when the capacitor is fully discharged. As you can see, the RC circuit converts the square wave to positive and negative spikes when the RC time constant is very short (a tenth of waveform's period). The importance of the RC time constant is illustrated in Fig. 3.4-9. When the time constant is made equal to one half the period of the input, as shown in Fig. 3.4-9 (c), less distortion results. The reason for this is that the capacitor never becomes fully charged. Even so, the output is still clearly distorted. When the time constant is much longer than the period of the input as shown in Fig. 3.4-9(d), the output is only slightly distorted.

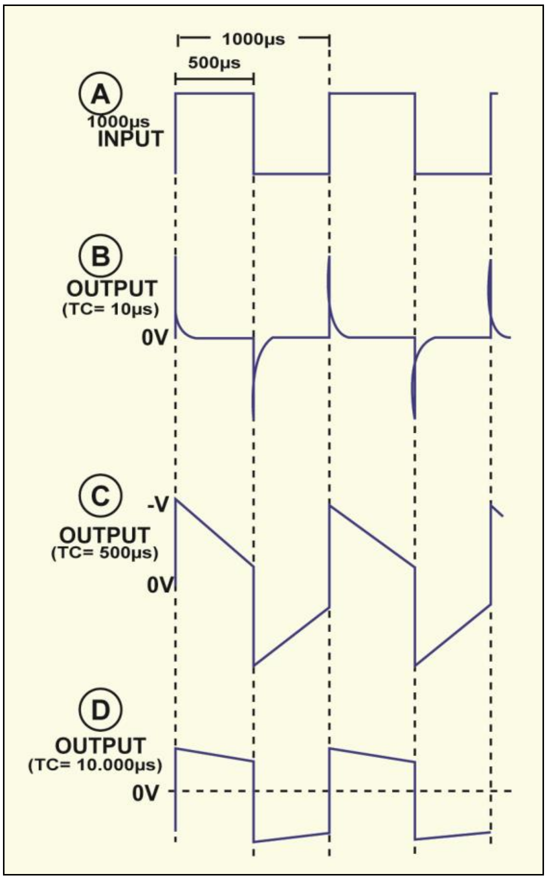


Fig. 3.4-9 Effects of RC Time Constant (TC)

INTEGRATOR

The integrator is a low pass filter which when fed with a square wave reproduces the low frequency components only, namely the flat parts of the waveform. (Ideally, only DC appears at the output). In practice, however, the output is a triangular wave with amplitude smaller than that of the square-wave input as shown in Fig. 3.4-10.

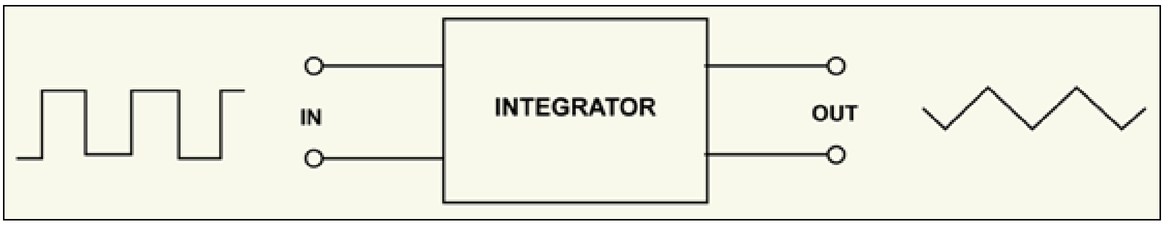


Fig. 3.5-10 Integration

An integrator circuit is shown in Fig. 3.4-11(a). Let's assume that the input to the circuit is a square wave as shown in Fig. 3.4-11(b). Let's also assume that the RC time constant is about one-tenth the period of the square wave. When the input square wave steps positive at time t_o, the capacitor begins to charge. Initially, the voltage across C_1 is 0. As C_1 charges, the voltages rises in very short time, as shown in Fig. 3.4-11(c). However, at t_1, the input voltage suddenly drops to 0 volts. Thus, the capacitor begins to discharge and the output voltage slowly drops to 0 volts.

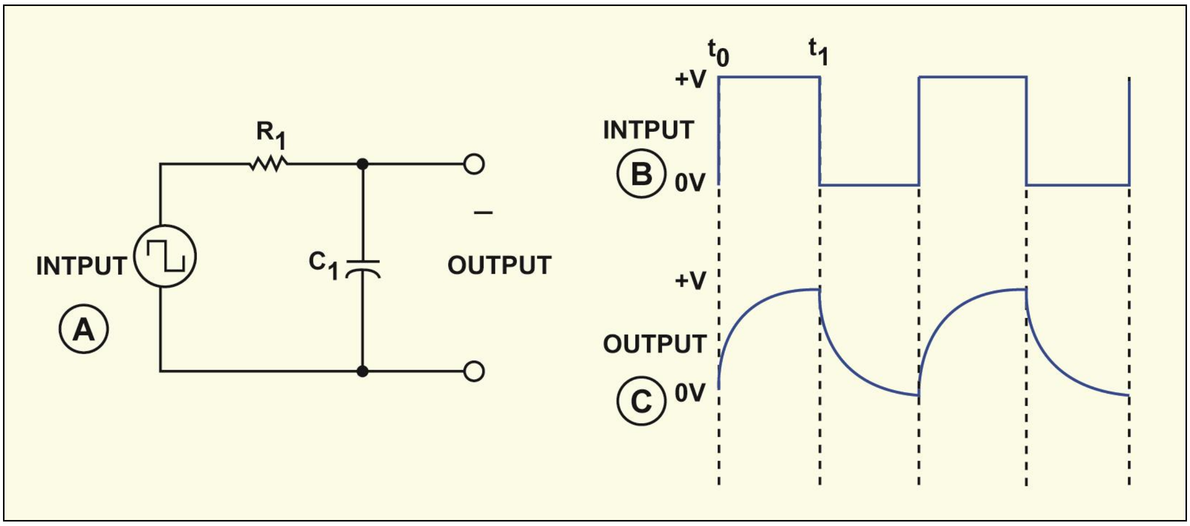


Fig. 3.4-11 Integrator and Its Waveforms

SCHMITT TRIGGER

The Schmitt trigger is a wave squaring circuit used to convert a sinusoidal or irregular input wave into a rectangular output wave. The circuit is basically a two-stage DC coupled transistors that employ regenerative feedback through a common emitter resistor to produce positive switching action. On and off times are initiated by the level of the input signal. The Schmitt trigger is an important circuit used for pulse shaping purposes. A common application of the Schmitt circuit is to convert a sine wave or trigger spikes to rectangular waveforms. The circuit for doing this is shown in Fig. 3.4-12.

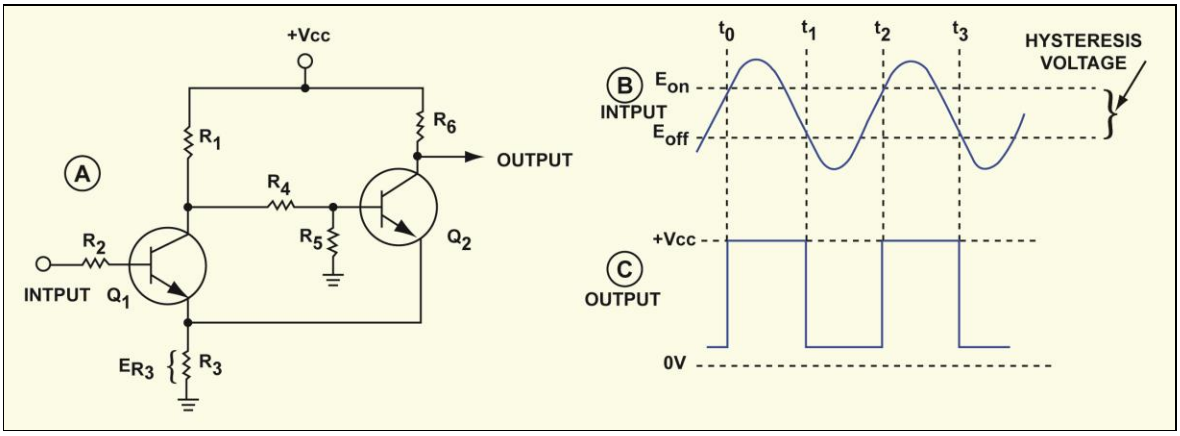


Fig. 3.4-12 Schmitt Trigger and its Waveforms

MONOSTABLE MULTIVIBRATOR

The monostable multivibrator Fig. 3.4-13 gets its name from the fact that it has one stables state. **The circuit is also called a one-shot multivibrator** because it is usually produces one output pulse for each input pulse. **The multivibrator can also be used to stretch pulses, or as a frequency divider.** So, the monostable multivibrator is a **pulse generator** and **similar to the Schmitt trigger**, except that it uses an RC timing circuit and feedback to insure that it returns to its initial condition automatically and independently of the input pulse. When a pulse is applied to the input the monostable is turned on and after a period of time determined by the RC circuit the circuit turns off returns to the "reset" state automatically.

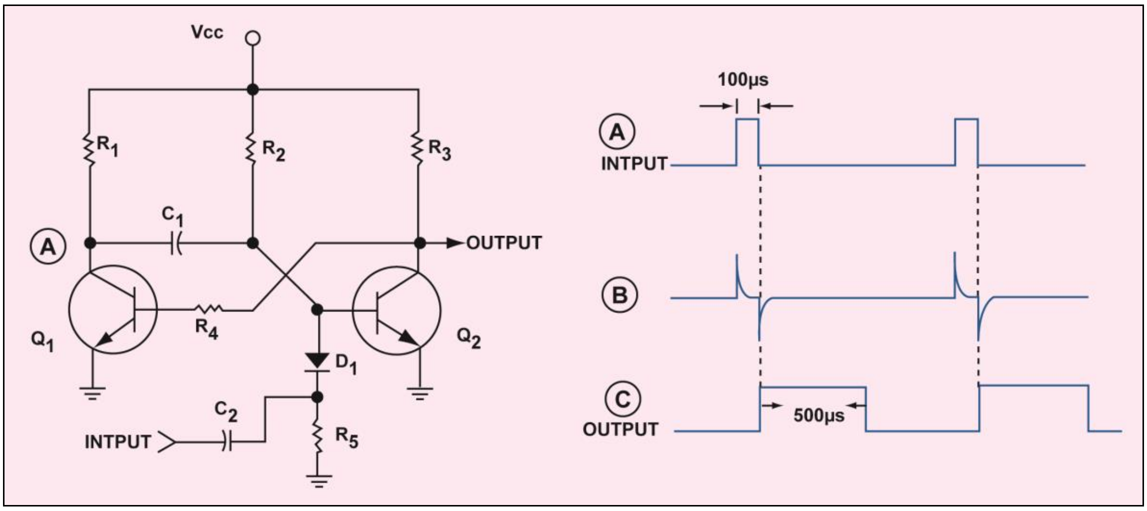


Fig. 3.4-13 Monostable Multivibrator and its Waveforms

Fig. 3.4-13(a) shows the schematic diagram of the monostable multivibrator. This circuit has two states. **The stable state** in our circuit is when Q_2 conducts and Q_1 is cut off. The other state is an **unstable state** where Q_1 conducts and Q_2 is cut off. The circuit rests in its stable state when it is not being triggered. The unstable state is initiated when the circuit receives an input trigger pulse. **The circuit stays in its unstable state for a period of time determined by the R_2C_1 time constant.** Again this is a function of the RC components in the transistor's base circuit. When the capacitor discharges, the circuit returns to its stable state and awaits the next input trigger.

The pulse width is approximately equal to:

$PW = 0.7\ R_2C_1$

The monostable multivibrator is used to produce a pulse of some specific duration. For this reason, it is sometimes called a pulse stretcher. Fig. 3.4-13(b, c) shows the input and output waveforms in a pulse stretching application.

Notice that the input pulses are only 100 microseconds wide while the output pulses are 500 microseconds wide. **The one-shot circuit can also be used to delay a pulse**. Suppose, for example, that we wish to delay a pulse by 1000 microseconds. The pulse is shown in Fig. 3.4-14 (a). A simple way to do this is to use the pulse to trigger a one-shot. Component values are chosen so that the one-shot produces a pulse that is 1000 microseconds wide, as shown in Fig. 3.4-14(b). This pulse can be converted to negative and positive spikes by a differentiator. The result is a negative pulse which occurs 1000 microseconds later than the original pulse. Since this pulse has the same characteristics as the original pulse, but occurs 1000 microseconds later, we have in effect, delayed the pulse by 1000 microseconds. The diode only passes negative pulses and a negative pulse would not affect the circuit's operation until after it returns to its stable state (Q_1 off and Q_2 on) as shown in Fig. 3.4-14(c).

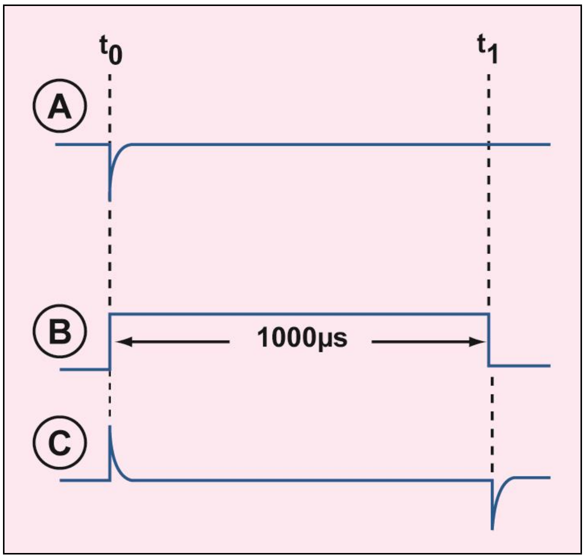


Fig. 3.5-14 Delaying a Pulse

ASTABLE MULTIVIBRATOR

The astable multivibrator produces a rectangular waveform without requiring an input signal. For this reason, **it is often called a free-running multivibrator**. It is a type of RC oscillator, which uses two transistor stages. A heavy regenerative feedback causes the transistor to alternate between cutoff and saturation. Consequently, the output is a square or rectangular waveform rather than a sine wave. The frequency of oscillation is determined by two RC time constants. An RC network controls the conduction time of each transistor.

The basic circuit is shown in Fig. 3.4-15. It consists of two transistors with the output of one connected to the input of the other. R_2 and R_3 bias the transistors into saturation. Capacitor C_1 couples the collector of Q_1 to the base of Q_2. In the same way, C_2 couples the collector of Q_2 to the base of Q_1. In normal operation, one transistor is cut off while the other is conducting. However, after a brief interval, the circuit changes states. The transistor, which was conducting cuts off while the transistor which was cut off starts conducting. The circuit oscillates back and forth between these two states. The output of the circuit is a rectangular wave which can be taken

from the collector of either transistor. The frequency of oscillation is primarily determined by the values of R_2, R_3, C_1 and C_2.

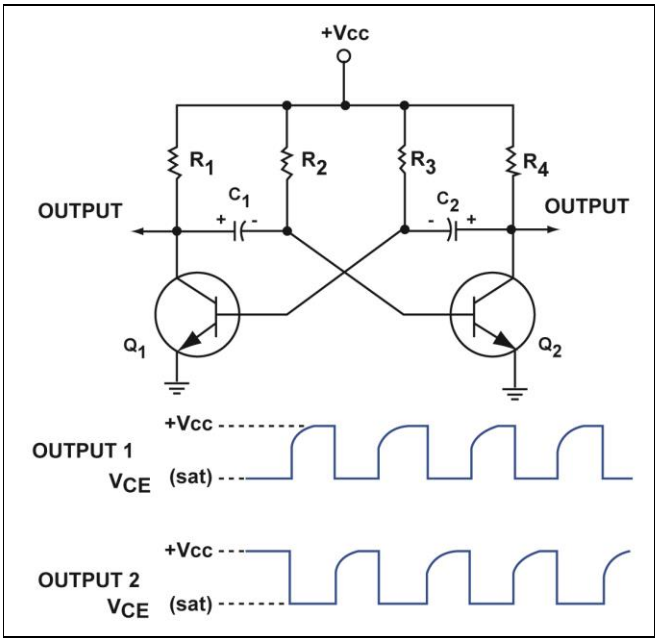


Fig. 3.4-15 Astable Multivibrator and its Waveforms

The oscillation frequency is determined by the R_2C_1 and R_3C_2 time constants. In other words the RC components in the base circuits determine the frequency of operation. R_2 and R_3 (the base resistors) are generally selected in order to ensure saturation of Q_1 and Q_2. Capacitors C_1 and C_2 are then chosen to produce the desired operating frequency. If $C_1 = C_2$ and $R_2 = R_3$, the frequency of oscillation is approximately equal to:

$$f = \frac{1}{1.4RC}$$

When the two transistor amplifier sections are balanced (identical), the positive half cycle will be equal to the negative half cycle. Unequal values of capacitors can be used to produce a wider or narrower positive pulse. In this case the waveform is said to be unbalanced (unequal pulse widths).

BISTABLE MULTIVIBRATOR

The third type of multivibrator is the bistable circuit. This circuit has two stable states. It normally has two inputs and two outputs. A pulse at one input sets the circuit to one of its stable states. A pulse at the other input resets the circuit to its other stable state. Because of its mode of operation, **the circuit is often called a flip-flop**. A set pulse flips the circuit to one state. A reset pulse flops the circuit back to its original state. The terms RS flip-flop is used in digital circuits to describe a block diagram's function that provides complementary outputs. **The RS flip-flop is a set-reset multivibrator, which is nothing more than a bistable multivibrator**. The basic flip-flop circuit is shown in Fig. 3.4-16. It consists of two transistor amplifiers connected so that the collector of each is coupled to the base of the other. As mentioned, the circuit has two stable states. When the circuit is set, Q_1 is saturated and Q_2 is cut off. When reset, Q_1 is cut off and Q_2 is saturated.

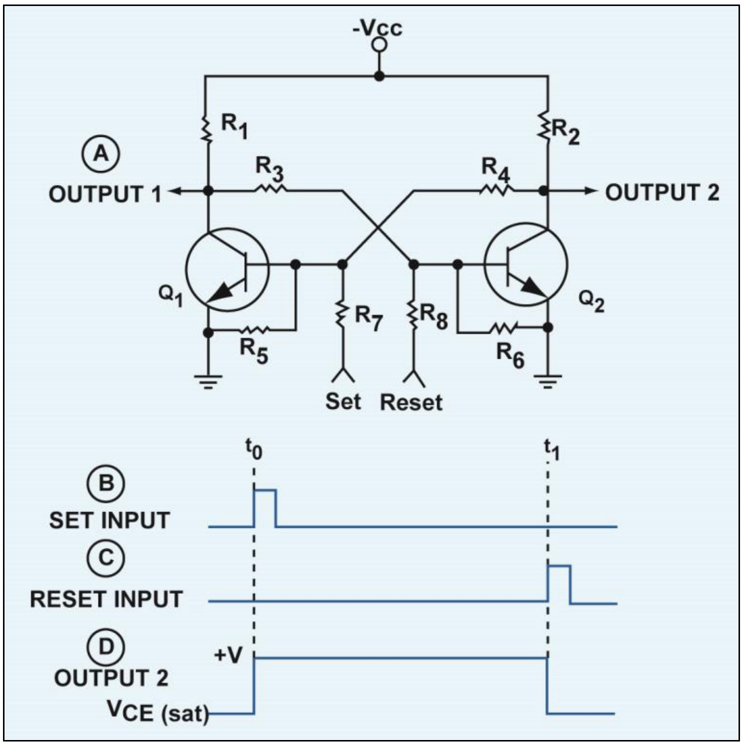


Fig. 3.4-16 Bistable Multivibrator and its Waveforms

OSCILLATORS

INTRODUCTION

An oscillator is a circuit that is capable of a sustained AC output signal obtained by converting input energy. Oscillators can be designed to generate a variety of signal waveforms, and they are convenient sources of sinusoidal AC signals for testing, control, and frequency conversion. Oscillators can also generate **square waves, ramps, or pulses** for switching, signaling, and control Fig. 3.4-17.

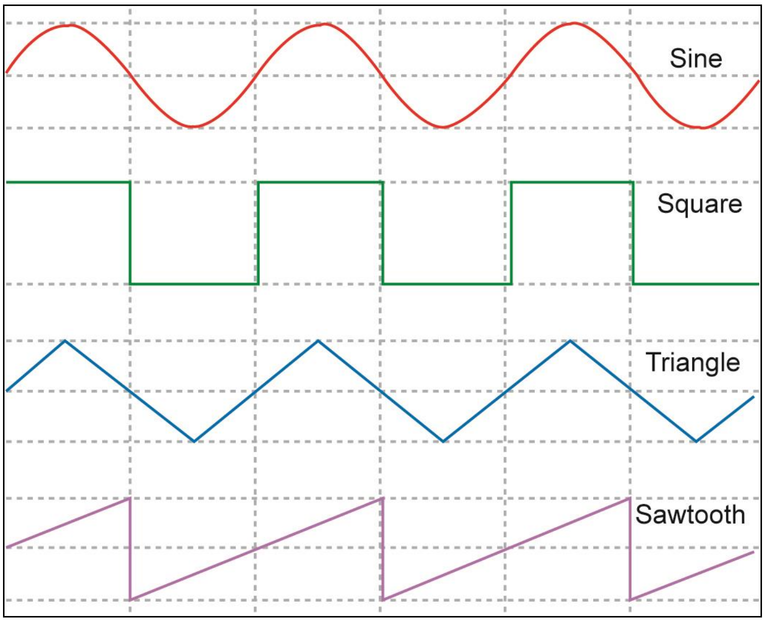


Fig. 3.4-17 Three Generator Signals

Simple oscillators produce sinewaves, but another form, the multivibrator, produces square or sawtooth waves. Fig. 3.4-18 shows a typical signal made by an oscillator.

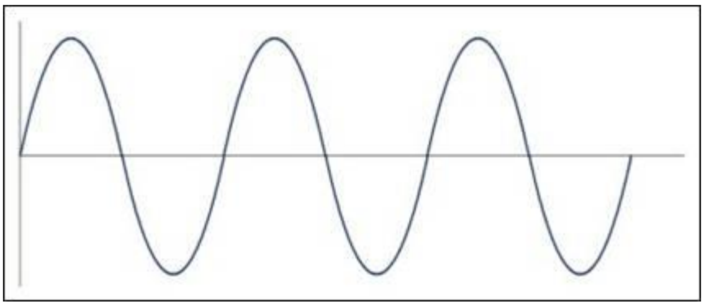


Fig. 3.4-18 Oscillator Signal

The common instrument used in laboratories is **sine/square generator**. This signal generator is an oscillator circuit with many practical uses. Fig. 3.4-19 shows the range and frequency controls on the Sine/Square Generator.

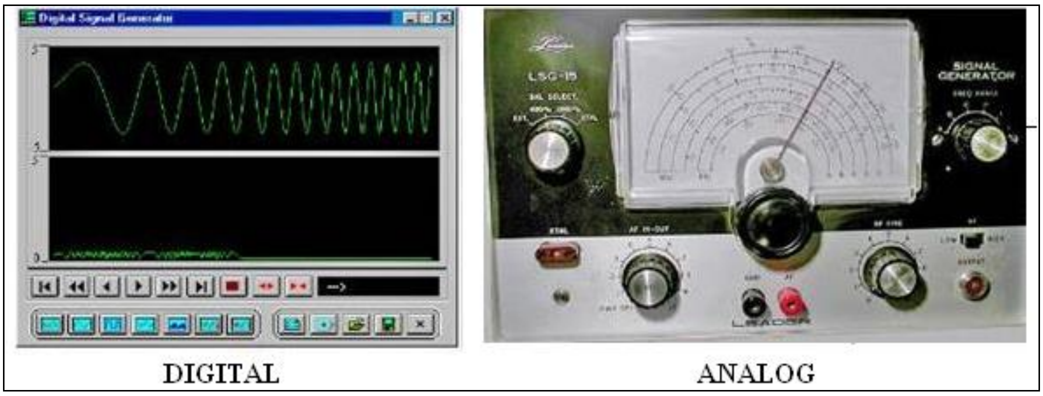


Fig. 3.4-19 Signal Generator

The basic oscillator circuit is an amplifier circuit. An amplifier can be changed into an oscillator by sending some of the output signal back to the input. The returning signal is called feedback. Fig. 3.4-20 shows how this change is occurred. Some of the output signal from the lower half of the secondary is returned to the base through the capacitor. Remember, capacitors conduct ac signals.

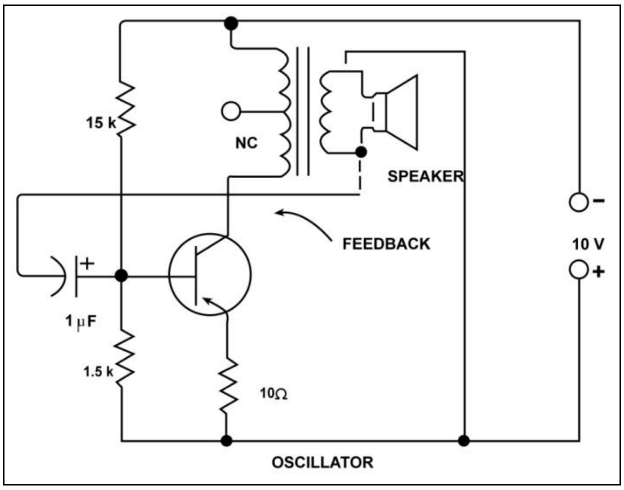


Fig. 3.4-20 Converting an Amplifier into an Oscillator

The signal at the base of the transistor is amplified and the process continues. The effect is much like the howl sometimes heard over a poorly adjusted public address system.

TUNED CIRCUIT

The frequency of the output signal from an oscillator can be controlled by a tuned circuit. Most oscillators use a tuned circuit; it is often a capacitor and inductor connected in parallel. The value of these parts controls the output frequency as shown in Fig. 3.4-21(a).

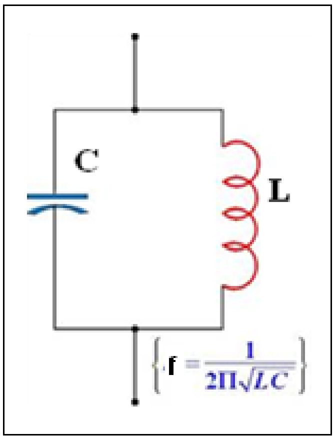


Fig. 3.4-21(a) Tuned Circuit

When voltage is removed from across the circuit, it begins to oscillate. The wave gets smaller (damping) because of resistance in the circuit. In electronics, this is called a ringing circuit. That is **damped wave** Fig. 3.4-21(b) generated by alternating current and the voltage drop across the circuit can be measured with an ac voltmeter.

It is possible to replace lost power in a tank circuit by adding more power. When the power is added in step with the oscillation between capacitor and inductor, power in the tank circuit is the maximum. The wave generated in a tuned circuit as shown in fig. 3.4-21(b).

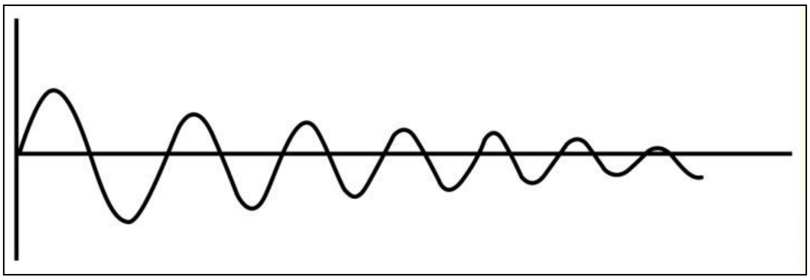


Fig. 3.4-21(b) The Wave generated in a Tuned Circuit

OSCILLATOR REQUIREMENTS

The following requirements are common to all oscillators:

1. An amplifier is necessary to replace circuit losses.
2. Frequency determining components are necessary to set the frequency of oscillation.
3. Positive feedback supplies a regenerative feedback to sustain oscillation.
4. The oscillator must be self-starting.

The voltage sine wave produced by an oscillatory circuit will not die away but will be maintained at constant amplitude if energy is supplied to the circuit to replace that dissipated in the resistive elements. This can be done by making the L-C circuit part of the feedback loop between the output and the input of an amplifier, as shown in Fig. 3.4-22.

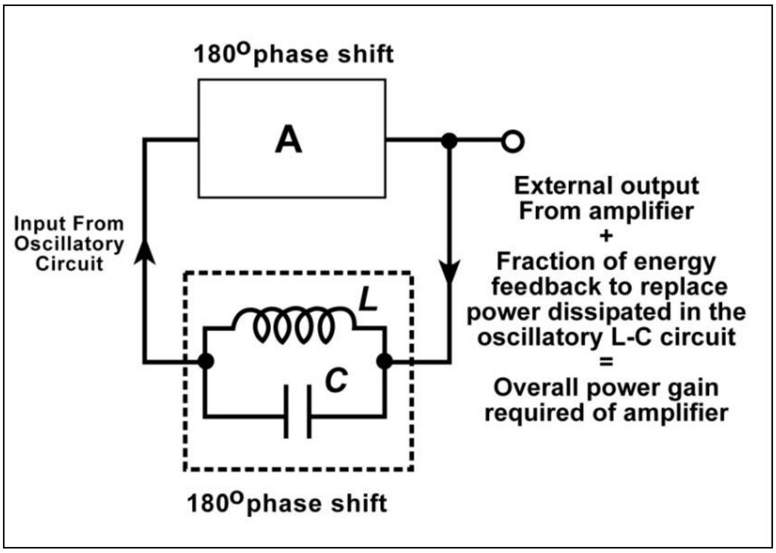


Fig. 3.4-22 L-C Feedback Loop Of an Amplifier

The following two essential conditions, that are mentioned earlier, must now be satisfied:

1. The amplifier must have sufficient gain to replace the power dissipated in the circuit.

2. The output from the amplifier must be in phase with the signal set up by the oscillatory circuit so that the amplifier output assists the alternating current in this circuit.

When the amplifier exactly replaces the power lost in the circuit, the loop gain around the complete circuit will be 1. If it is less than 1, the circuit will stop oscillating; if it is greater than 1, the circuit will oscillate and the oscillations will build up in amplitude until they are limited in some way. It is common to arrange the circuit feedback so that the loop gain is greater than 1, though not necessarily much greater. This ensures that the circuit will commence oscillating without difficulty. The build-up of amplitude which then follows is restricted by certain circuit conditions and the system stabilizes itself at a loop gain which is equal to 1.

COMMON-EMITTER OSCILLATORS

Fig. 3.4-23 shows the basic circuit of a common-emitter amplifier having an oscillatory circuit wired into its collector circuit. For this reason this kind of oscillator is known as the **tuned-collector oscillator**. Looking at the amplifier itself, you will recognize the conventional common-emitter configuration discussed in the previous lessons. Resistors R_1 and R_2 form a potential divider so that there is a constant dc voltage at the base of the transistor which biases it to the correct operating point on the characteristic. The capacitor C_1 simply by-passes R_2 at the frequency of oscillation so that as far as the ac. signal is concerned junction of R_1 and R_2 is effectively short-circuited by the low reactance of C_1.

The oscillatory circuit L-C represents the feedback element connecting the amplifier output at the collector to the input at the base. The oscillatory voltage generated in the L-C circuit is coupled back to the base input by means of a coupling (or tertiary) winding L_1, which is a small coil wound in proximity to the main inductor L. This arrangement forms a transformer so that any change in the current flowing in L

influences the magnetic field set up around L and causes an emf to be induced in L_1 in accordance with Faraday's law of induction. Clearly, the amount of energy fed back can be controlled by alteration of the coupling between L and L_1, i.e. the spacing of these coils can be modified until the required condition for proper circuit performance is established. A phase shift of zero or 360° is now required around the loop.

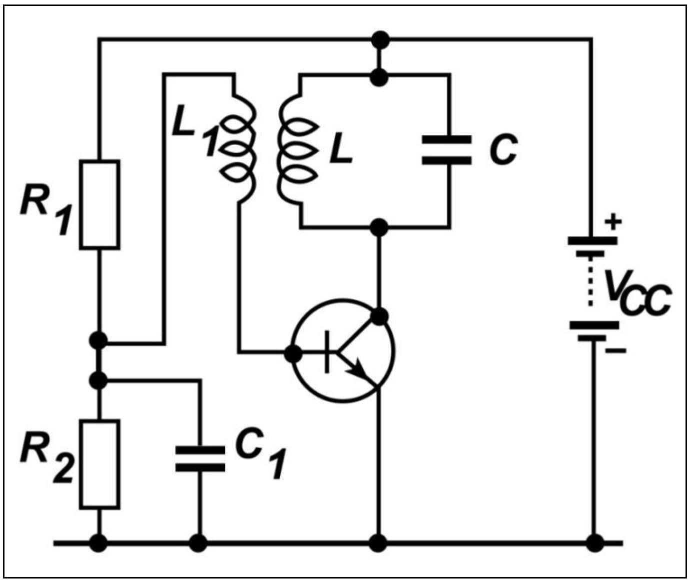


Fig. 3.4-23 Basic Circuit of a Common-Emitter Amplifier

A transistor in common-emitter connection introduces a 180° phase shift as we have already seen; to obtain a total shift of 360° round the loop, the transformer must be connected so that it also introduces a 180° phase shift. This is easily arranged; by reversing the connections to one or other of its windings, the transformer will give an output that is either in phase or 180° out of phase with its input. On switching on the dc (V_{CC}) supply, collector current commences to build up. This sets up a changing magnetic field in L and the resulting flux links with the neighboring turns of L_1 so that an emf is induced in the base circuit. This emf will develop between base and emitter as an input voltage V_i and if this is in the proper phase it will augment the collector current flow. Once established in this way the L-C circuit will set up an oscillation by the interchange of energy between its component parts, a fraction of this oscillatory energy will be fed back to the base circuit as input to the amplifier, and the energy dissipated during each cycle in the resistances of the circuit will be made up by the dc

source feeding the oscillator. Hence the oscillator converts direct current to alternating current. The tuning of the oscillator can be carried out by varying either C or L in the oscillatory circuit. If the oscillator is going to be used at one single frequency it is usual to employ a fixed capacitor for C and adjust L. For a variable frequency output, it is more convenient to make C adjustable and a standard variable capacitor can be used for this purpose. In oscillators required to cover a wide range of frequency, the value of L may also be made variable by switching in different coils to the oscillatory circuit.

OSCILLATOR CLASSIFICATIONS

Most oscillators work on the positive feedback, which means that feedback is necessary to sustain oscillation. Oscillators are generally classified according to their frequency determining components.

These three general classifications are:

- LC oscillators
- RC oscillators
- Crystal oscillators

LC OSCILLATORS

LC Oscillators use a tuned circuit consisting of either a parallel-connected or series-connected capacitor or inductor to set the frequency.

The LC oscillator is a circuit that adds a tuned circuit to an amplifier circuit. The tuned circuit makes the oscillator work at the resonant frequency of the tuned circuit. The oscillator feedback adds energy lost in the tuned (LC) circuit because of resistance. As a result, the output of the tuned circuit is a continuous, undamped ac wave. Fig. 3.4-24 shows a simple LC oscillator like the one you will make. The

transformer primary and the 0.22 μ F capacitor make a tuned circuit. This is only one of many different tuned oscillators in use.

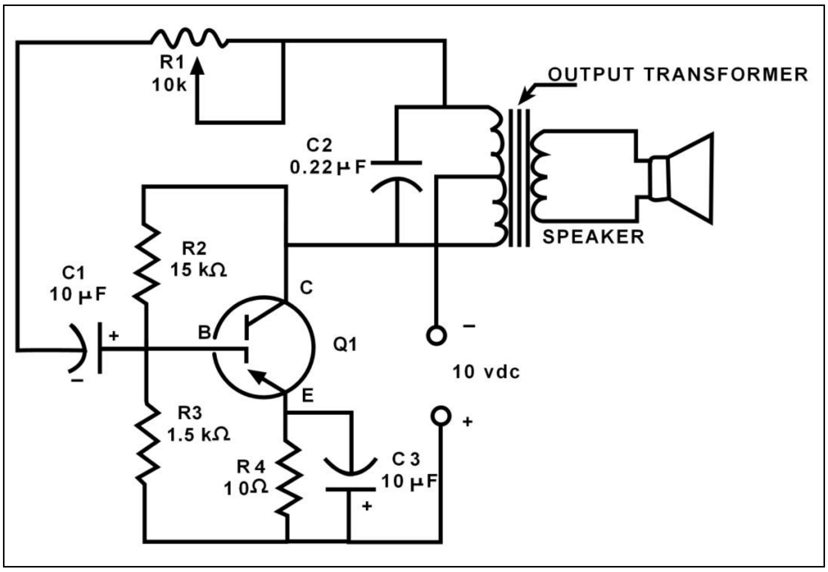


Fig. 3.4-24 LC Oscillators

RC PHASE SHIFT OSCILLATOR

- Usually audio-frequency oscillators.
- Considerable power loss.
- Inexpensive to build.
- Capacitor feedback.

RC phase shift Oscillator Circuit is shown in Fig. 3.4-25

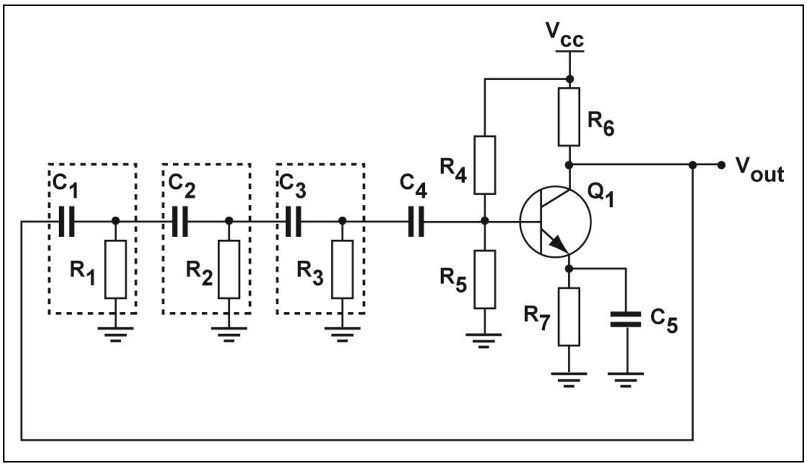


Fig. 3.4-25 RC Phase Shift Oscillator

CRYSTAL OSCILLATOR

Applications where extreme oscillator stability is required, the LC oscillator is unsatisfactory. Temperature changes, component aging, and load fluctuations cause the oscillator to drift, which makes the oscillator unstable. When a high degree of stability is required, crystal oscillators are generally used.

A crystal oscillator is an electronic circuit that produces electrical oscillations at a particular designed frequency determined by the physical characteristics of one or more crystals, generally of quartz, positioned in the circuit feedback loop. A **piezoelectric effect** causes a crystal such as quartz to vibrate and resonate at a particular frequency. The quartz crystal naturally oscillates at a particular frequency, its fundamental frequency that can be **hundreds of megahertz**. However, in applications where extreme oscillator stability is required, the LC oscillator is unsatisfactory. Temperature changes, component aging, and load fluctuations cause the oscillator to drift, which makes the oscillator unstable. When a high degree of stability is required, crystal oscillators are generally used. The crystal oscillator is generally used in various forms such as a frequency generator, a frequency modulator and a frequency converter.

CRYSTAL CHARACTERISTICS

Crystal materials produce piezoelectricity. That is, when mechanical pressure (stress) is applied to a crystal, a difference in potential is developed. Fig. 3.4-26 illustrates this point. In Fig. 3.4-26 (a), a normal crystal has its charges evenly distributed and is therefore neutral. If force is applied to the sides of the crystal, as shown in Fig. 3.4-26 (b), the crystal is compressed and opposite charges accumulates on the sides. Thus, a difference in potential is developed.

If pressure is applied to the top and bottom, Fig. 3.4-26 (c), the crystals is stretched and again opposite polarities appears across the crystal. Thus, if the crystal is

alternately compressed and stretched, an AC voltage can be generated. Therefore, a crystal can convert mechanical energy into electrical energy.

Just the opposite effect occurs if AC voltage is applied to a crystal. The electrical energy from the voltage source is converted to mechanical energy in the crystal.

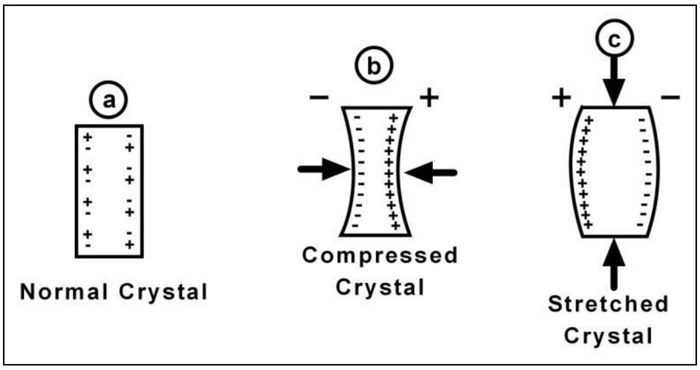


Fig. 3.4-26 Mechanical Stress Applied To Crystal

Fig. 3.4-27 illustrates this point. The AC input signal causes the crystal to stretch and compress, which creates mechanical vibrations that correspond to the frequency of the AC signal.

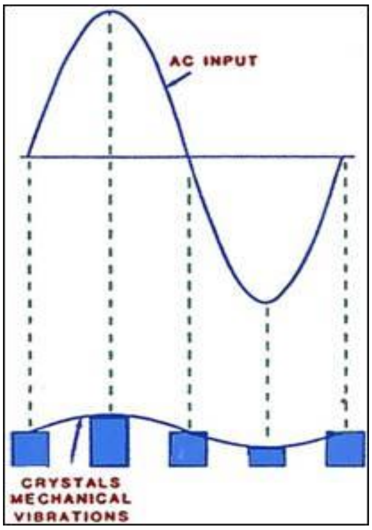


Fig. 3.4-27 Crystal Mechanical Vibrations

EQUIVALENT CRYSTAL CIRCUITS

A crystal is usually mounted between two metal plates and a spring applies mechanical pressure to the plates. The metal plates secure the crystal and also provide the electrical contact. The crystal is then placed in a metal casing or holder. The schematic symbol for a crystal is derived from the way it is mounted and represents the crystal slab held between two plates, as shown in Fig. 3.4-28. The word crystal is often abbreviated "XTAL" or "Y" on schematics.

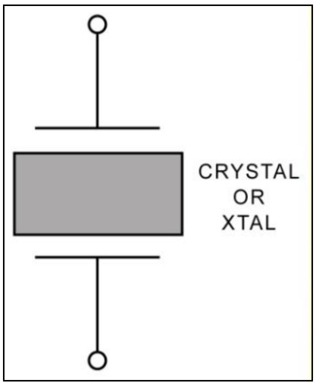


Fig. 3.4-28 Schematic Symbol for a Crystal

The crystal alone looks electrically like a series-resonant circuit, as shown in Fig. 3.4-28. In the series equivalent circuit, inductance (L) represents the crystal's mass that effectively causes vibration; (C) represents crystal stiffness, which is the equivalent of capacitance; R is the electrical equivalent of internal resistance caused by friction.

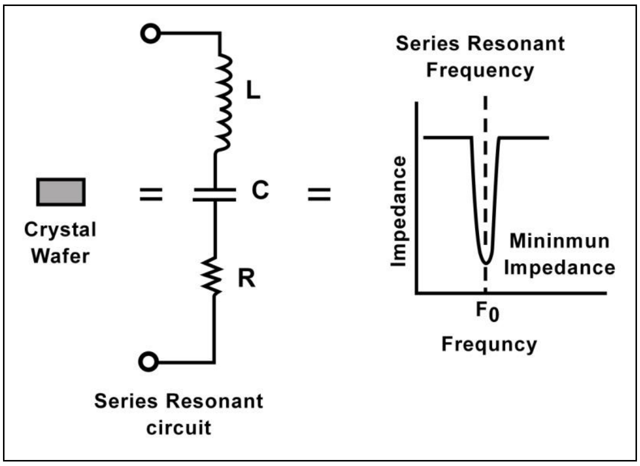


Fig. 3.4-29 The Crystal Wafer is a Series-Resonant Circuit

When the crystal is mounted between metal plates, the equivalent circuit is modified, as shown in Fig. 3.4-30. The metal mounting plates now appear as a capacitor, C_P, in parallel with the series-resonant circuit of the crystal.

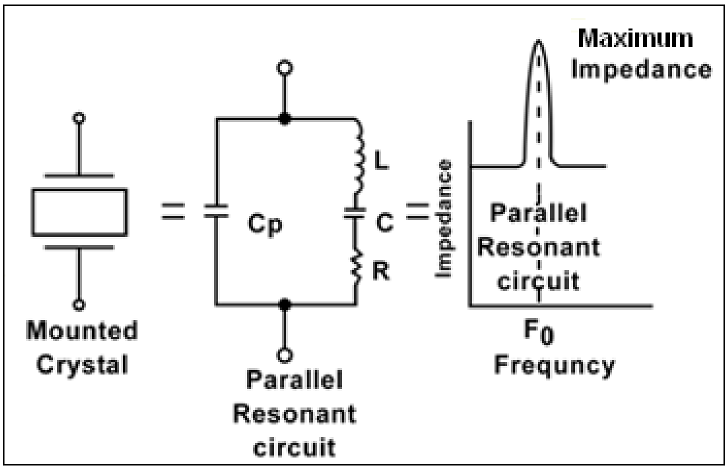


Fig. 3.4-30 the Crystal Wafer Resonant Circuit

CRYSTAL OPERATION

A typical crystal oscillator is shown in Fig. 3.4-31. Many different circuits are available, but the one shown is a **Pierce oscillator**. Transistor Q_1 is connected as a common-emitter amplifier. Capacitor C_E grounds the emitter for ac signals. DC bias and bias stability are provided by the voltage divider arrangement of R_A - R_B across the collector supply voltage V_{CC}, and by emitter resistor R_E. Resistor R_C is the collector load resistor. Crystal Y_1, connected between collector and base, serves as the frequency determining component. Capacitors C_{F1} and C_{F2} are effectively in parallel with Y_1 by way of Q_1 base-emitter junction. Crystal Y_1 operates in the parallel resonant mode in conjunction with C_{F1} and C_{F2} together, they provide the phase shift and feedback required to sustain oscillation.

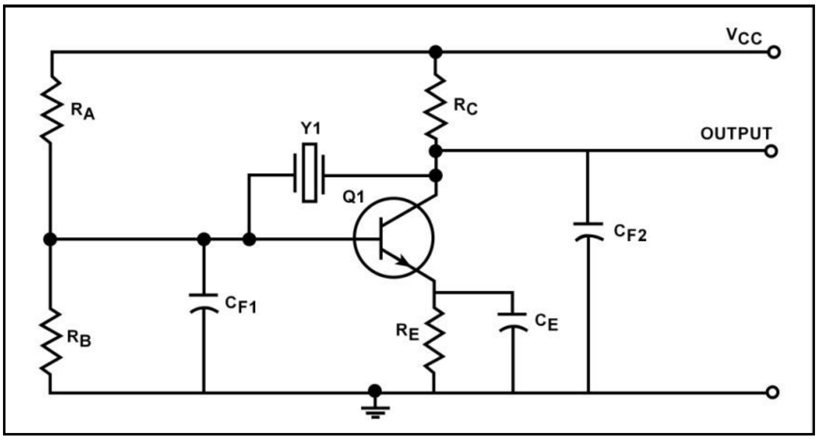


Fig. 3.4-31 Pierce Oscillator

Now consider one cycle of operation. At rest, the crystal is unstressed and no electrical voltage appears across the plates of the crystal holder. When collector voltage is applied, the capacitive effect of the crystal holder and R_A-R_B junction provides a positive base voltage that acts as forward bias on Q_1. Simultaneously, the crystal is stressed by this collector potential and a piezoelectric charge appears across the crystal.

THE HARTLEY CRYSTAL OSCILLATOR

Hartley crystal oscillators, is connected in series frequency (Fig. 3.4-32). Also, the LC tank network must be tuned to the series-resonant frequency of the crystal. When the oscillator is operating at the crystal frequency, the crystal's equivalent series-resonant circuit offers minimum opposition to current and feedback is maximum. If the oscillator drifts away from the crystal frequency, the impedance of the crystal increases drastically, reducing feedback. This forces the oscillator to return to the natural frequency of the crystal. Therefore, when the crystal is series-connected, it controls feedback. Note the tapped inductors which identify this circuit as a Hartley oscillator.

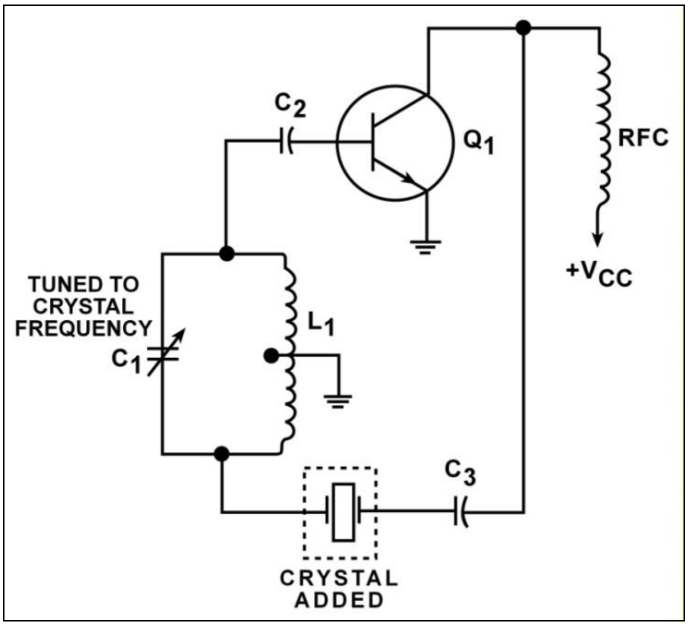


Fig. 3.5-32 Hartley Crystal Oscillator

THE COLPITTS CRYSTAL OSCILLATOR

The colpitts oscillator can be crystal controlled in the same manner as the Hartley oscillator Fig. 3.4-33.

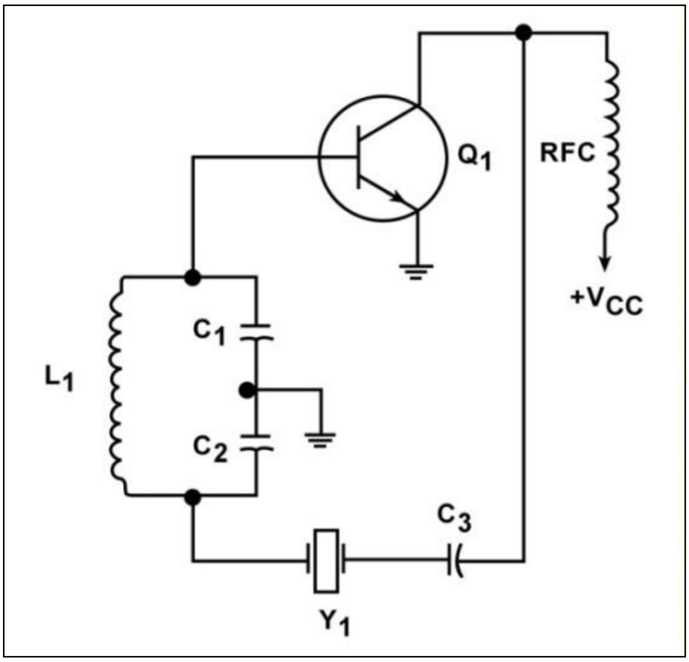


Fig. 3.4-33 Colpitts Crystal Oscillator

SUMMARY

- Oscillators can also generate square waves, ramps, or pulses for switching, signaling, and control.
- The frequency of the output signal from an oscillator can be controlled by a tuned circuit.
- The three general classifications of oscillators are:
  - LC oscillators
  - RC oscillators
  - Crystal oscillators
- RC oscillators can generate signals from a few hertz (Hz) up to several megahertz (MHz).
- A crystal oscillator uses a crystal as the frequency determining component.
- A crystal can have both series and parallel resonance effects.
- A piezoelectric effect causes a crystal such as quartz to vibrate and resonate at a particular frequency.

FORMULAS

$$F = \frac{1}{1.4RC}$$

PW = 0.7 R_2C_1

GLOSSARY

Clipping	The preventing the output of a circuit from exceeding a predetermined voltage level without distorting the remaining part of the applied waveform
Clamping Circuit	Is used to change the DC reference voltage of a waveform. It clamps the top or bottom of a waveform to a DC voltage
Differentiator	A high pass filter
Integrator	A low pass filter
Oscillators	A circuit that is capable of a sustained AC output signal obtained by converting input energy
Drift	Gradually transfer
Brought about	Approximate

REVIEW EXERCISE

1. Fill in blanks:

a. The differentiator is a ______________________ filter.

b. A clamping circuit is used to ________________________________.

c. A clamping circuit clamps the ____________ or ________________ of a waveform to a DC voltage.

d. The integrator is a ____________________ filter

e. The Schmitt trigger is a wave squaring circuit used to convert a _____________or ______________ input wave into a __________ output wave.

f. Oscillators can generate _______________,____________or _____________ for switching, signaling, and control.

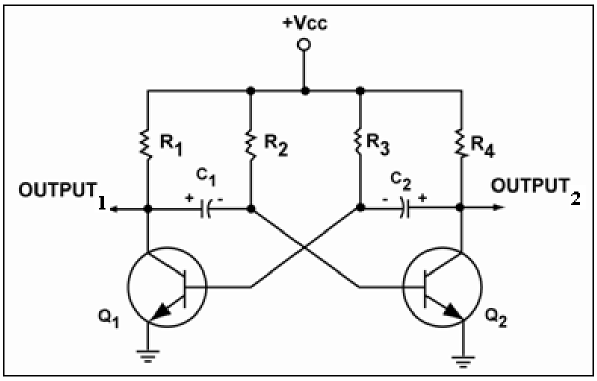
g. Most oscillators use a tuned circuit; it is often a_____________and connected in parallel.

h. The word crystal is often abbreviated "________________" or "___" on schematics.

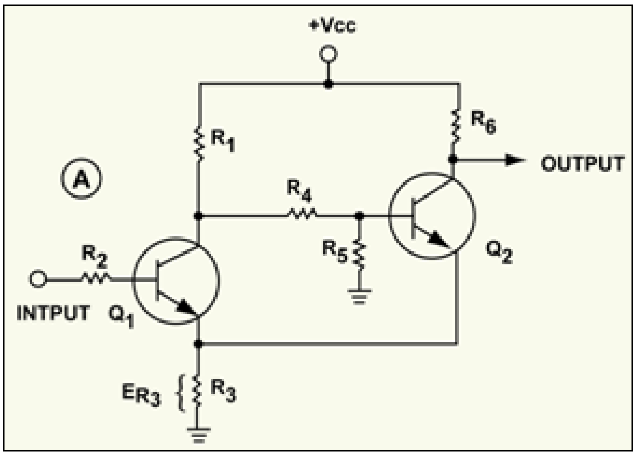
2. Check True for the correct sentence and False for the wrong sentence:

	TRUE	FALSE
a. -Check True for the correct sentence and False for the wrong sentence:		
b. - Square waves are simple waveforms consisting of a fundamental sine wave and an The integrator is a low pass filter		
c. - The Differentiator is a high pass filter.		
d. - The astable multivibrator produces a square waveform without requiring an input signal.		

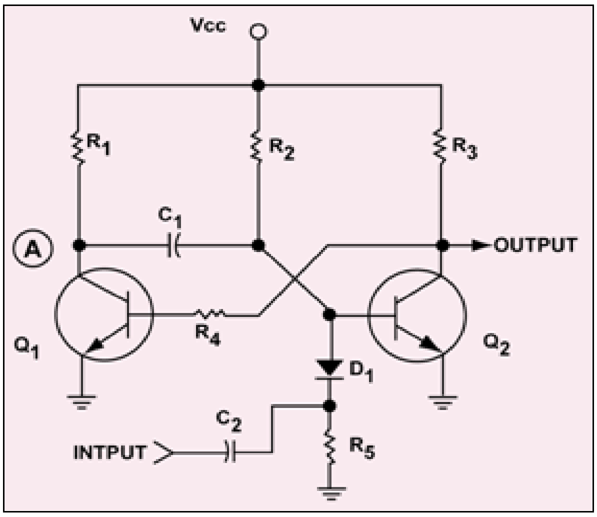
3. Write the name of the following circuits:



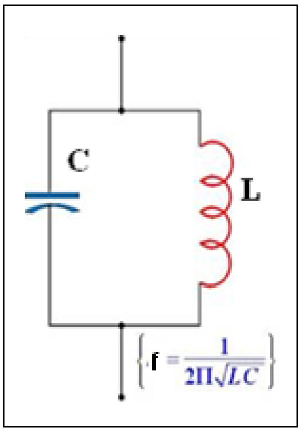
a. - ______________________________



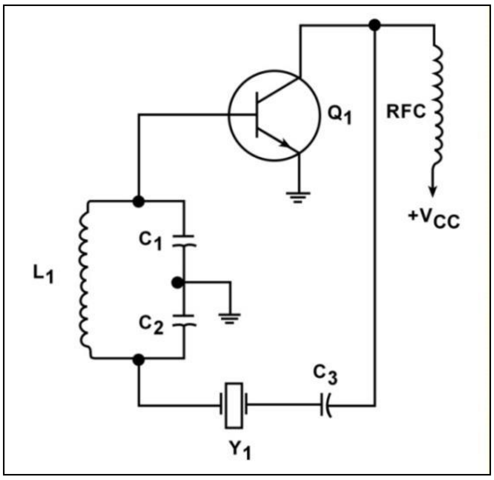
b. - ____________________________



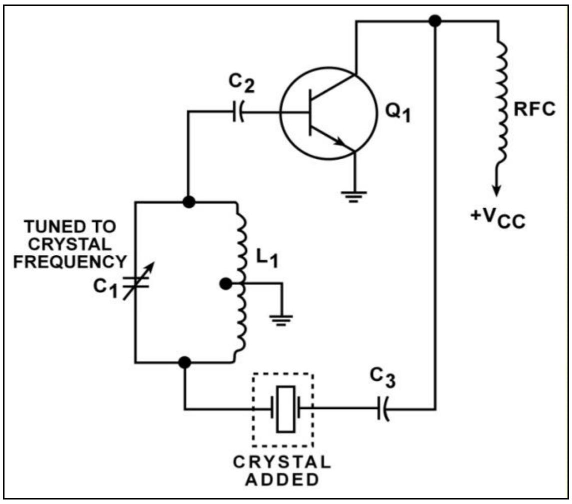
c. - ___________________________


C
L
$f = \frac{1}{2\Pi\sqrt{LC}}$

d. - ________________________


Q1
RFC
+VCC
C1
L1
C2
C3
Y1

e. - __________________________


C2
Q1
RFC
+VCC
TUNED TO
CRYSTAL
FREQUENCY
C1
L1
C3
CRYSTAL
ADDED

f. - _________________________

TASK 3.4-1

DRIVEN RECTANGULAR-WAVE SHAPING CIRCUITS

OBJECTIVES

Upon completion of this task, the participants will be able to:

- Evaluate a zener diode slicer circuit.
- Examine the operation and characteristics of driven multivibrators.
- Examine the operation of a Schmitt trigger circuit.

TOOLS, EQUIPMENT & MATERIALS

- ET-3100 Trainer
- VOM (multimeter)
- 2 - Silicon diodes (57-27)
- 1 - Red LED (412-640)
- 1 - Green LED (412-642)
- 1 - 100 ohm resistor
- 1 - 1500 ohm resistor
- 1 - 4700 ohm resistor
- 1 - 22 k ohm resistor
- 2 - 0.1 microfarad capacitors
- Oscilloscope
- 2 - NPN silicon transistors (417-801)
- 1 - 555 Timer IC (442-53)
- 1 - Red LED (412-640)
- 1 - Variable capacitor (31-77)
- 3 - 1000 ohm resistors
- 2 - 3300 ohm resistors
- 2 - 10 k ohm resistors
- 1 - 100 k ohm potentiometer (10-1142)

PROCEDURE

1. Construct the circuit shown in Fig. 1-1. Turn on the ET-3100 and set the supply voltage to +10 volts.

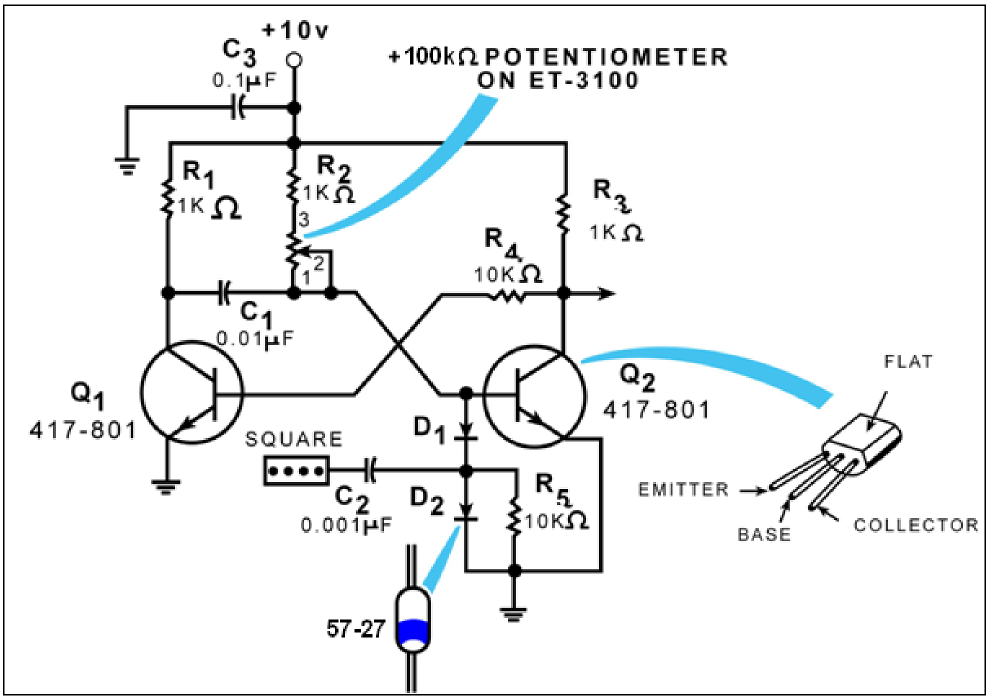


Fig. 1-1 Monostable Multivibrator

2. Set the generator to its lowest frequency.
3. Connect the external trigger input of your oscilloscope to the SQUARE terminal on the Trainer. Set the triggering mode to external and the slope switch to "-". View the waveform at the SQUARE terminal. Adjust the oscilloscope so that two complete cycles of the square wave are displayed. Note the points on the screen at which the negative-going edges of the square wave occur.
4. Set the 100 K ohm potentiometer fully clockwise. View the waveform at the collector of Q_2. Note the points on the screen at which the leading edge of the output pulses occur. These points correspond to the negative-going edges of the input pulses.
5. While viewing the waveform at the collector of Q_2, slowly turn the 100 k ohm potentiometer counterclockwise.
6. The output pulse width ________________________increases/decreases.
7. Measure the output pulse width with the potentiometer fully clockwise.

   PW = ____________________ microseconds.

   Compute the pulse width using the formula F = 0.7 RC.

   PW = ____________________ microseconds.

8. Measure the output pulse width with the potentiometer fully counterclockwise. PW = ____________________ microseconds. Compute the pulse width using the formula F = 0.7 RC. PW = ____________________ microseconds.

   Replace C_2 with the variable capacitor (31-77) and adjust the capacitor fully clockwise. Monitor the tie point between the diodes with the oscilloscope. Adjust the variable capacitor between fully clockwise and fully counterclockwise and note the change on the differentiated input waveform. _____________________________ Increased/decreased/stayed the same.

   Move the scope probe to the collector of Q_2 and note the change in the output waveform as you adjust the variable capacitor fully clockwise and then fully counterclockwise. ____________________ stayed the same/increased/decreased.

9. Construct the circuit shown in Fig. 1-2. Turn on the Trainer and set the supply voltage to +10 volts. As shown, connect one end of a long jumper wire to ground. Temporarily leave the other end disconnected.

   If you **do not** wish to use the oscilloscope or voltmeter to determine which transistor is conducting you may use the LEDs as your indicator. When Q_1 is conducting the green LED will be lit. When Q_2 is conducting the red LED will be lit. You may notice that both LEDs are lit at the same time. However, the LED indicating the ON condition will be much brighter than the other LED. This is because there is some current flowing through the LED connected to the collector of the off transistor. This current is flowing through the emitter-base junction of the conducting transistor.

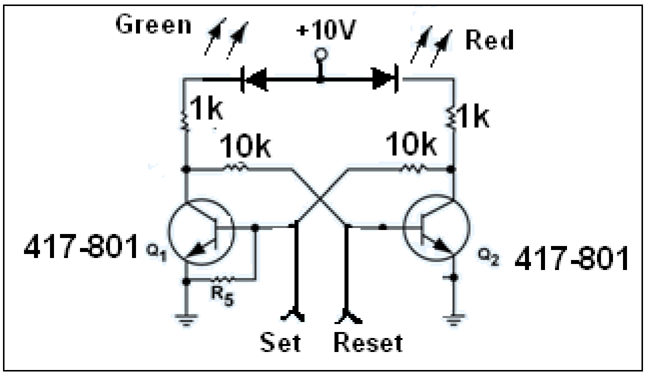


Fig. 1-2 Bistable Multivibrator

10. Connect the free end of the jumper wire to the SET input. Measure the collector voltage of Q_1. Is Q_1 cut off or conducting? ___________________conducting/cut off.

    Measure the collector voltage of Q_2. Is Q_2 cut off or conducting?__________ yes/no.
11. Disconnect the jumper wire from the SET input. Measure the collector voltage of Q_1. Is Q_1 still cut off? _______________ yes/no.

    Measure the collector voltage of Q_2. Is Q_2 still conducting? __________ yes/no.
12. While monitoring the collector voltage of Q_1 repeatedly touch the free end of the jumper wire to the SET input. Does this change the state of the flip-flop? ___________ yes/no.
13. Connect the free end of the jumper wire to the RESET input. Measure the collector voltage of Q_1. Is Q_1 cut off or conducting? _______________________________.

    Measure the collector voltage of Q_2. Is Q_2 cut off or conducting? ______________________________ cut off/conducting.
14. Disconnect the jumper wire from the RESET input. Measure the collector voltages of Q_1 and Q_2. Is Q_1 still conducting? ___________. Is Q_2 still cut off?_______ yes/no.
15. While monitoring the collector voltage of Q_1, repeatedly touch the free end of the jumper wire to the RESET input. Does this change the state of the flip-flop. ________________ Yes/no.
16. While monitoring the collector voltage of Q_1, alternately touch the free end of the jumper wire to the SET and RESET inputs.
17. While monitoring the collector voltage of Q_1, alternately touch the free end of the jumper wire to the collectors of Q_1 and Q_2. Notice that the flip-flop can be set by temporarily grounding the collector of Q_2 and reset by temporarily grounding the collector of Q_1.
18. Construct the circuit shown in Fig. 1-3. Turn on the Trainer and set the supply voltage to +10 volts.

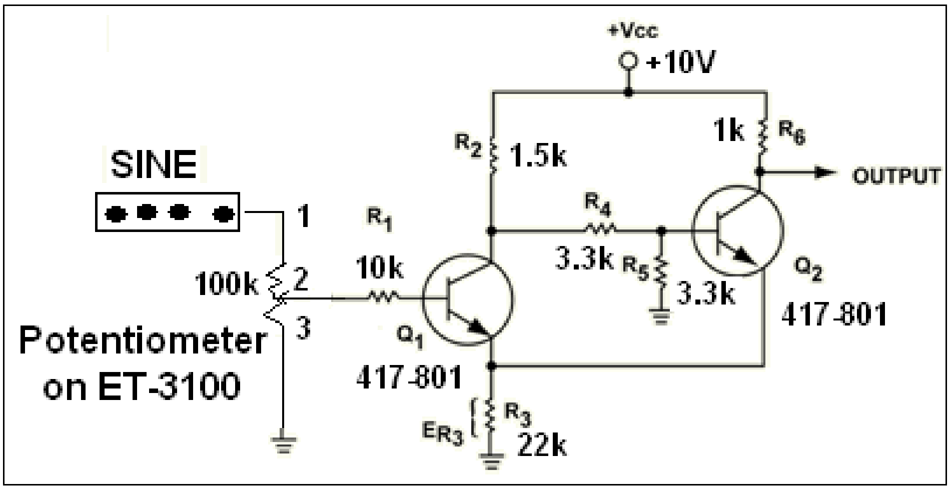


Fig. 1-3 Schmitt Trigger

19. Set the generator frequency to 1 kHz. Set the 100 k ohm potentiometer fully clockwise. Connect the probe of the oscilloscope to the collector of Q_2.
20. Slowly turn the potentiometer counterclockwise until a pulse waveform appears at the collector of Q_2. As the potentiometer is turned further counterclockwise, the width of the positive pulse:________________________ increases/decreases
21. Turn the potentiometer fully counterclockwise. Trigger the oscilloscope externally using the square wave from the SQUARE terminal. Set the slope switch to "+".
22. View the waveform at pin 2 of the potentiometer. Draw two cycles of the waveform in Fig. 1-4.
23. View the waveform at the collector of Q_2. Draw two cycles of this waveform in Fig. 1-4b.

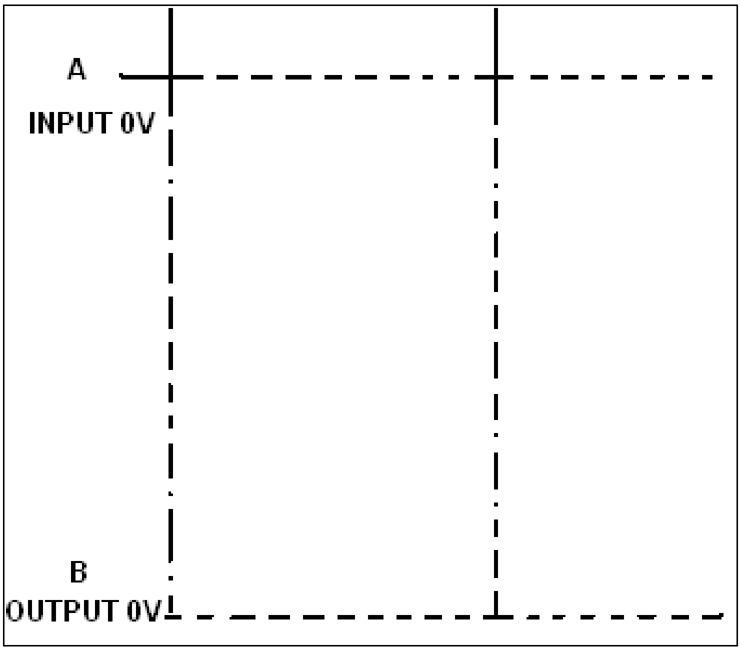


Fig. 1-4 Plot of Waveforms Observed in steps 21 and 22

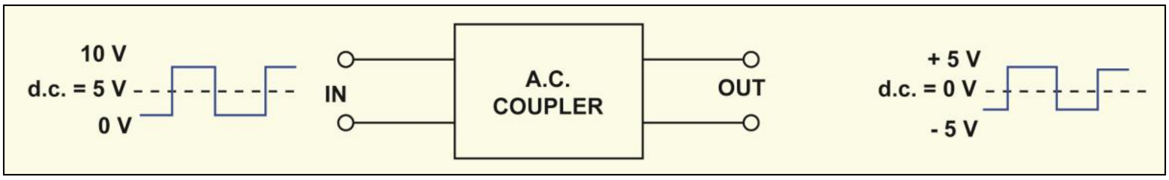


Fig. 1-5 Typical Waveforms for Steps 21 and 22

TASK 3.4-2
VERIFY OPERATIONS OF OSCILLATORS

OBJECTIVES

Upon completion of this task the participants will be able to:

- Stabilize a basic colpitts oscillator by inserting a crystal in the feedback path.
- Evaluate a simple Pierce oscillator.

TOOLS, EQUIPMENT & MATERIALS

- 47 microhenry inductor (40-1659)
- NPN transistor (417-801)
- 3.58 kHz crystal (404-238)
- 4.7 pF, 24 pF, 47 pF capacitors (1 each)
- .01 pF, 001 pF capacitor
- 560 Ω, 1500 Ω, 8200 Ω, 10 kΩ, 47 kΩ, 100 kΩ, 1 MΩ resistors (1 each).

PROCEDURE

1. Construct the circuit shown in Fig. 2-1. Make sure you connect transistor Q_1 as indicated in the pictorial. Otherwise, the collector and emitter terminals may inadvertently be reversed and the oscillator will not function. You can identify inductor L_1 by the yellow and violet lines painted on it.

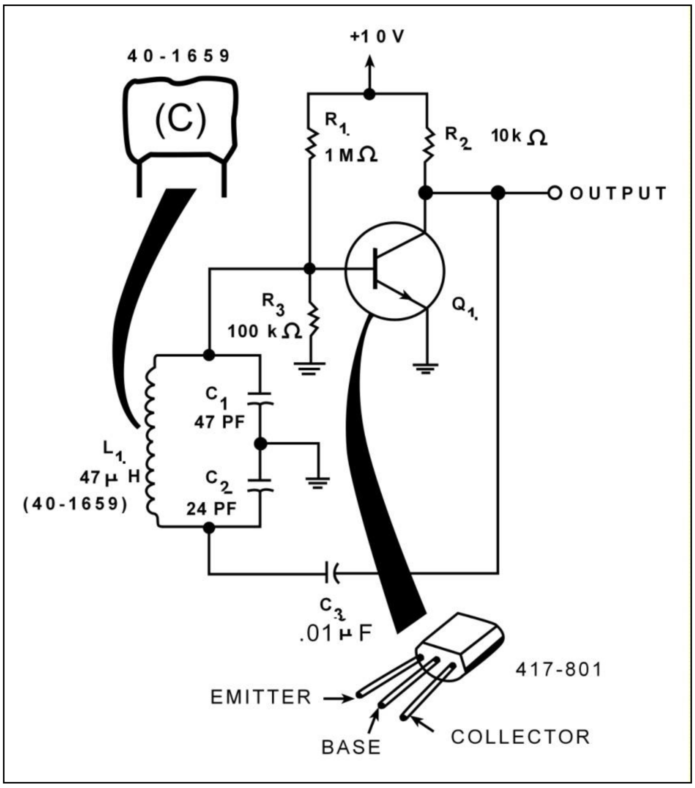


Fig. 2-1 Circuit for Step 1 (Colpitts Oscillator)

2. Set the power supply voltage to +10 volts. Turn on your Trainer and connect the oscilloscope probe between the output and ground. Observe the output waveform and record the frequency below. The sine wave may be distorted, but this is not important at this time.

   F_O = ________________ Hz

   The circuit you constructed is a ______________ oscillator

3. As you observe the output waveform, grasp the 24 pF capacitor tightly between your thumb and forefinger. Do not touch the capacitor's leads. After a few seconds, record the oscillator frequency.

   F_O = ________________ Hz

   Although the shift in frequency appears small, it is large enough to effect the oscillator frequency a significant amount. Record the difference between this frequency and that obtained in step 2.

   Frequency Difference = ____________ Hz

4. Turn off the Trainer and connect the 3.58 kHz crystal in the feedback path as shown in Fig. 2-2. With the crystal connected in this manner, it is operating in the ________________ resonant mode.

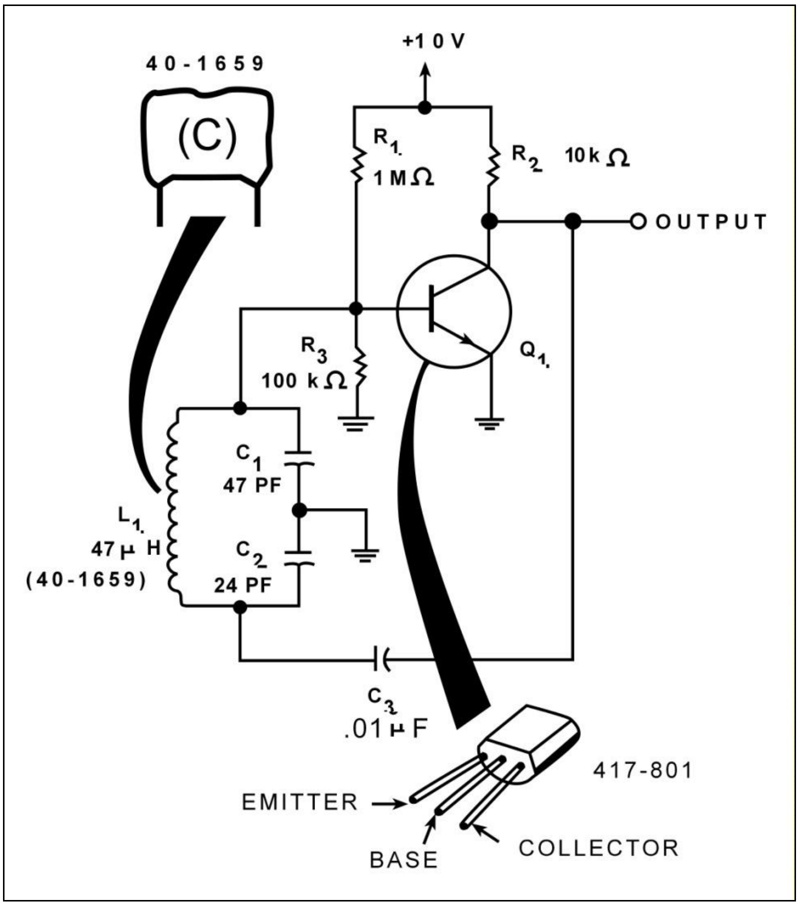


Fig. 2-2 Series Resonant Colpitts Crystal Oscillator

5. Turn on the Trainer and observe the output waveform. The crystal is now controlling the resonant frequency of the oscillator. Record the frequency below.

   F_O = ________________ Hz

6. Again grasp the 24 pF capacitor between your thumb and forefinger. Observe the output and record the frequency below.

   F_O = ________________ Hz

   Did the frequency vary as much as in step 3? _______________ Yes/no

7. Turn off the Trainer. Refer to Fig. 2-3 and remove the 47 microhenry inductor and connect the crystal in its place. Be sure to connect the .01 pF feedback capacitor to the tank circuit as shown.

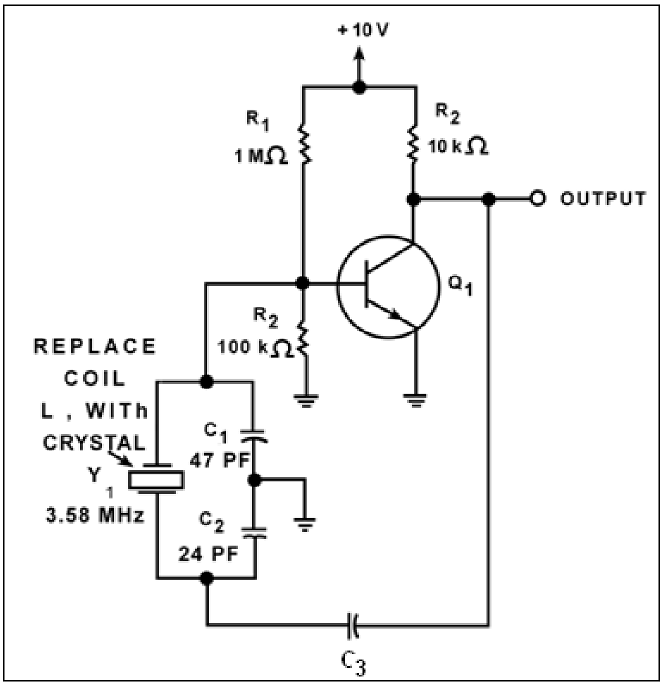


Fig. 2-3 Parallel Resonant Colpitts Crystal Oscillator

8. In Fig. 2-4 this is a pierce oscillator that functions at frequency of:

   f_0 =_______ Hz

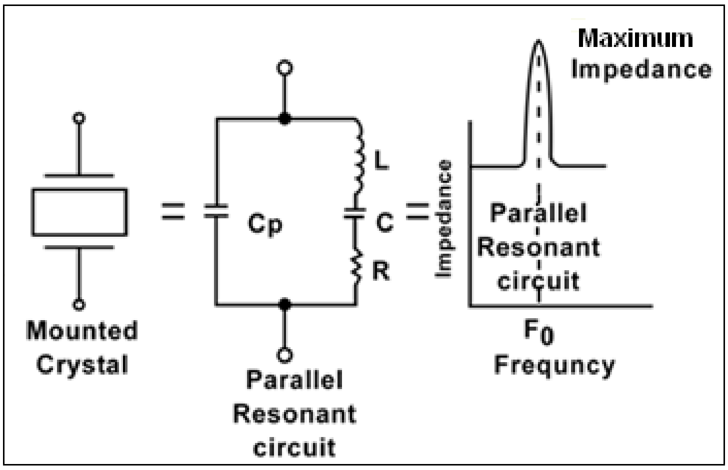
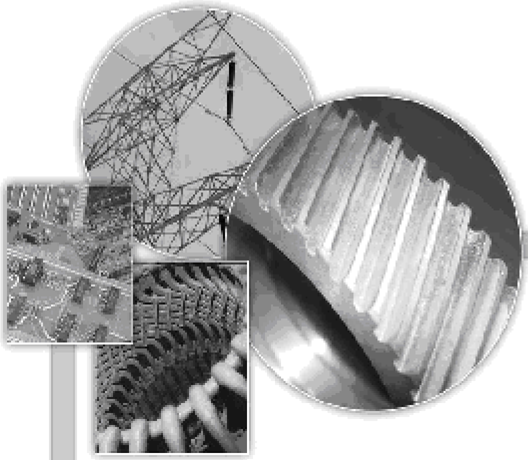


Fig. 2-4 Parallel Connected Crystal and Its Response Curve



UNIT 4

LESSON 4.1

INTRODUCTION TO POWER SOURCES AND SEC NETWORK

LESSON 4.1
INTRODUCTION TO POWER SOURCES
AND SEC NETWORK

OVERVIEW

This lesson familiarizes the participants with SEC Electrical Power System.

OBJECTIVES

Upon completion of this lesson, the participants should be familiar with:

- Generating Sets and Network Generation Plants
- Electrical Power Network
- Network Action
- Power Plants in SEC
- Power Transmission and Voltage Levels
- Power System Protection
- Faults, Causes and Effects
- Importance Of Protective Relaying
- Protective Zones
- Primary And Backup Protection

SEC POWER SYSTEM

The purpose of any electrical power system is to generate electricity or (electrical power) and transfer it from the source to the user. The source is where electricity comes from. A Power Plant is a source and the user is where electricity is used. Transmission lines and switchgear connect between source and user. Fig. 4.1-1 shows a simple electrical system. The source is a single power plant and the user is a village. The disadvantage of this system is the user will be without electric power if power plant is out of operation.

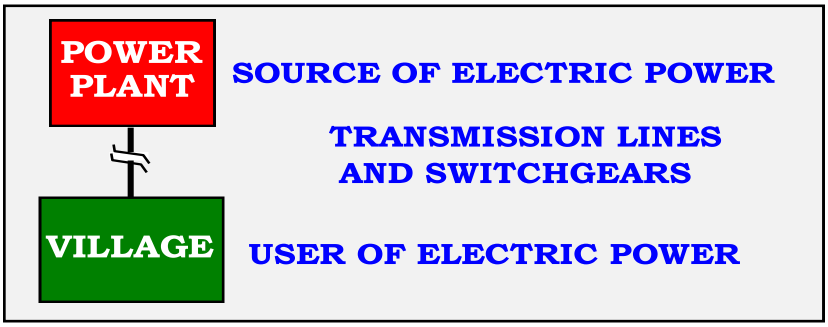


Fig. 4.1-1 Simple Power System

ELECTRICAL POWER NETWORK

A network is an advanced type of electrical power system. It consists of several separate power plants (steam, gas and combined), they are connected together by transmission lines or cables and switchgear (transmission substations) and distribution substations to transfer the Electric power from generation plants to the residential, commercial and industrial loads, as shown in Fig. 4.1-2. This way, each power plant in the network acts as a part of a 'team' instead of working alone.

The terms **Electrical Power System** and **Electrical Power Network** are used to describe this team. **SEC Power System** and **SEC Network** both mean the same thing.

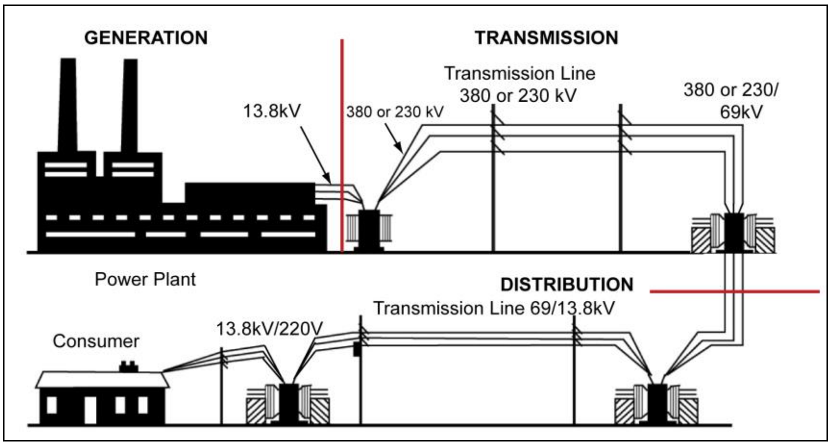


Fig. 4.1-2 Electrical Power Network

GENERATING SETS

Each generator in a power plant is driven by its own 'prime mover' (also called driver). A turbine (either gas or steam) is a prime mover.

The term **Generating Set** includes both the turbine and generator. Diesels, gas turbines and steam turbines are the more commonly used prime movers for the generation of electrical power. Additionally, the steam turbine can be employed in combination with gas turbine for combined cycle operation. Each generator is attached to its own prime mover to make up a single unit or a set. **The term generating set includes both a turbine and a generator** as shown in Fig. 4.1-3.

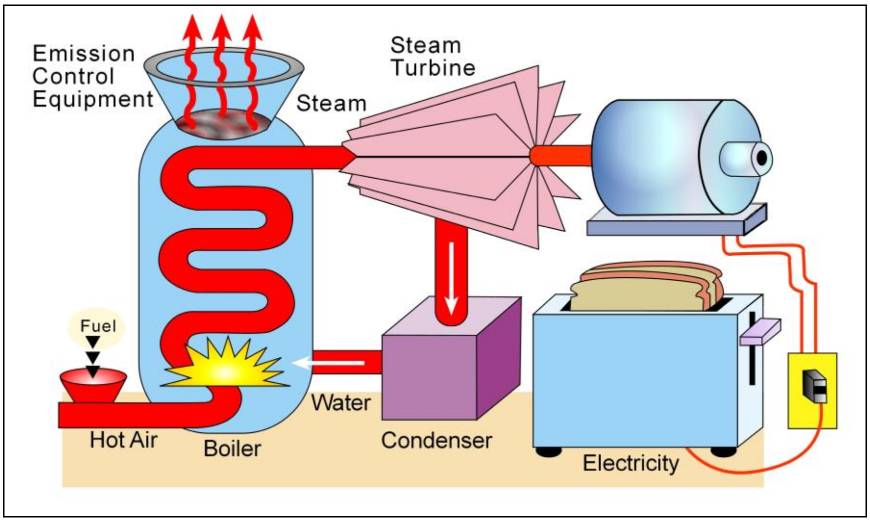


Fig. 4.1-3 Generating Sets

The generator capacity (maximum output or maximum load) is expressed in electrical units, for example, ten Mega-Watts (10 MW). **One Horse Power** of mechanical energy is equal to **746 Watts** of electrical energy. So a generator rated at 10 MW maximum output (ten million Watts) requires a diesel engine or gas turbine rated at (10,000.000 divided by 746) Horse Power to drive it or 13,400 HP plus approximately 10% allowances for energy losses in overcoming friction, air resistance and unavoidable heat). That is about 14,500-15,000 HP, as shown in Fig. 4.1-4.

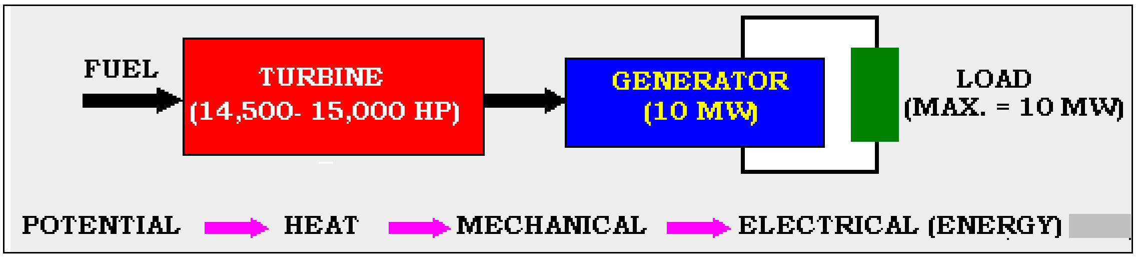


Fig. 4.1-4 Energy Conversion

1H.P. = 746 Watts 1MW = 10^6 Watts

10MW = 10×10^6 Watts = $\frac{1\text{H.P.}}{746\text{ W}}\times10\times10^6\text{W} = 13400\text{ H.P.}$

Allowing 10% electro-mechanical losses

Total H.P. required = 13400 H.P. + (13400 H.P. × 0. 1) = 14740 H.P ≈ 15000 H.P.

POWER PLANTS IN SEC

The SEC network consists of many power plants Fig. 4.1-5. They are connected to supply power to the four areas in the Kingdom. The users in this area are many, using large amounts of electricity. The users vary from the smallest village to the largest city and from a small store to factories. The homes use electricity for heating, lighting, air conditioning, refrigerating and other electrical devices.

The size and generating capacity of each plant in SEC is different. The larger plants are in areas where user demand is high. The smaller plants are in areas where user demand is low.

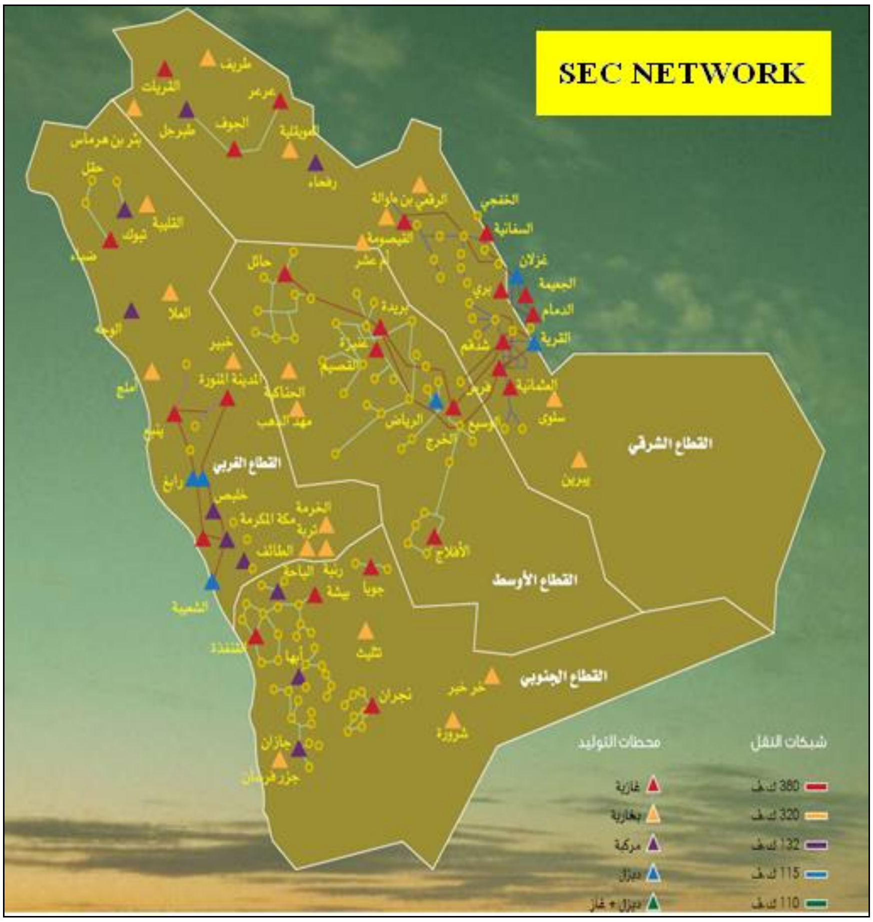


Fig. 4.1-5 SEC Power Plant and HV Transmission Lines

LOAD

The amount of electric power needed or demanded by the user at any particular time is usually referred to as **Load**. The load can vary a great deal from hour to hour, from day to day and from one part of the year to another.

For example, in the evening more power is used for lighting and cooking; on holidays, less power is used by industry. In very hot weather, power is used more for air conditioning. In very cold weather, more power for heating is required and so on.

Before installing generators, it is necessary to know how much electricity is likely to be needed by the user as shown in Fig. 4.1-6. The user being a small town or village. If the maximum predicted load (or estimated peak demand) for electrical power by the village is taken as 10 MW, the generating capacity of the power plant must not be less than 10 MW.

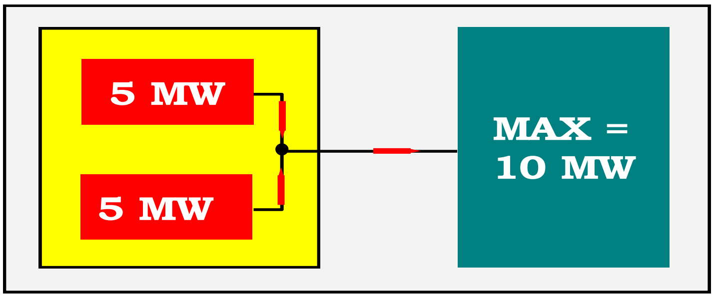


Fig. 4.1-6 Suitable Power Plants supplying adequate Power to Customers

NETWORK ACTION

In Fig. 4.1-7, the large Load Area B (20 MW) is fed from Station-b, with 4 generators; while Load Area C (5 MW) is supplied by the single Unit in Station-c. Station-a is producing (15 MW); with 12 MW going to Area A, 1 MW to Area E and 2 MW to Area B. (**Note that**: Area B requires 20 MW but Station-b can produce a maximum of only 18 MW, as two of its generating sets are 'off-line').

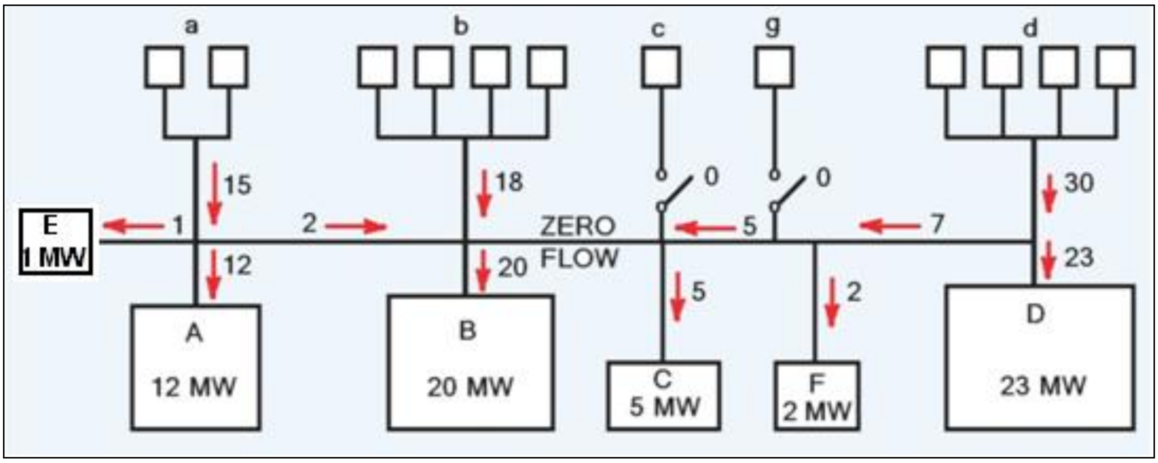


Fig. 4.1-7 Power Flow in Typical Network

Power Plant-c (one generator) is also off-line, so Plant-d (four operational generating sets) is simultaneously supplying its own Area D (23 MW) **plus** Areas C and F (5 MW + 2 MW). At this particular time, there is **zero flow** in the transmission line between Plant-b and Plant-c. Plant-g is a small, single-generator 'emergency' or 'booster' station, which can be put on-line to help out during abnormal conditions.

The power plants, in a network, can supply loads anywhere in the network. But it is easier and cheaper to supply loads to the local area so, there is a need for transmitting power over long distances.

Long distance transmission lines serve two purposes:

- Supply power to isolated secondary load areas.
- Transfer electrical power between power plants.

POWER TRANSMISSION AND VOLTAGE LEVEL

SEC transmits large amounts of power not only to users, but also between plants. SEC uses high voltage transmission lines. SEC uses 380 kV (kilo-Volts), 230 kV, 115 kV and 69 kV transmission lines between **Bulk Supply Point (BSP)** and **Grid Station (GS)**. Fig. 4.1-8 shows a part of Single Line Diagram for SEC Network.

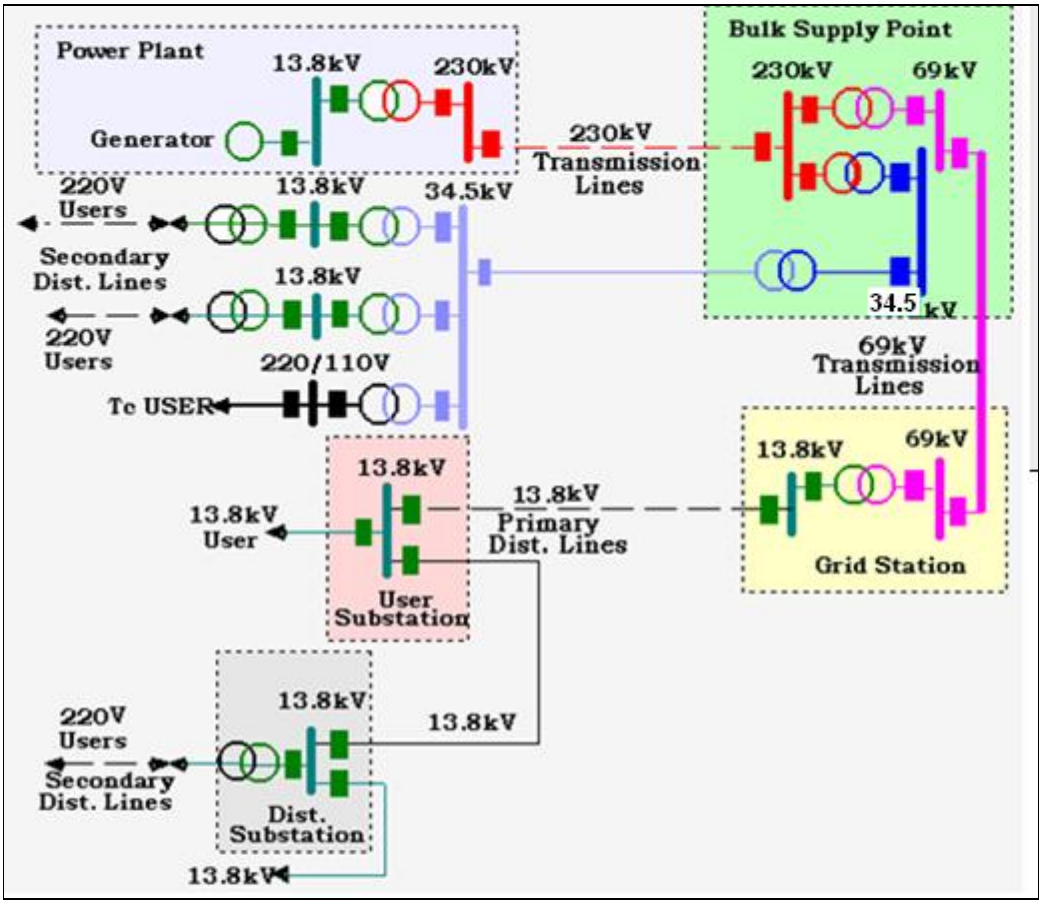


Fig. 4.1-8 Power Network Stages and Voltage Level

INTRODUCTION TO POWER SYSTEM PROTECTION

Protective relaying is necessary with each part of the network and no part of the power system is left unprotected. The choice of protection depends upon several aspects such as type and rating of the protected equipment, its importance, location, probable abnormal conditions, cost, etc. Between generators and the final load points, there are several electrical equipment and machines of various ratings requiring adequate protection.

The protective relaying senses the abnormal conditions in a part of the power system and gives an alarm or isolates that part from the power system. The relays are compact, self-contained devices, which respond to abnormal conditions. The relays distinguish between normal and abnormal conditions. Whenever an abnormal

condition develops, the relays close their contacts to trip the circuit breaker. Current from the battery supply flows in the trip-coil of the circuit breaker, the circuit breaker opens and the faulty part is disconnected from the supply. The entire process, (occurrence of fault, operation of relay, opening of circuit breaker and removal of faulty part from the system) is automatic and fast.

Circuit Breakers are switching devices, which can interrupt **normal currents** and **fault currents**. Besides relays and Circuit Breakers, there are several other important components in the protective relaying scheme, such as protective **current transformers, protective relays, time-delay relays, auxiliary relays, secondary circuits, trip circuits, auxiliaries and accessories**, etc**.** Protective relaying is teamwork of these components as shown in Fig. 4.1-9.

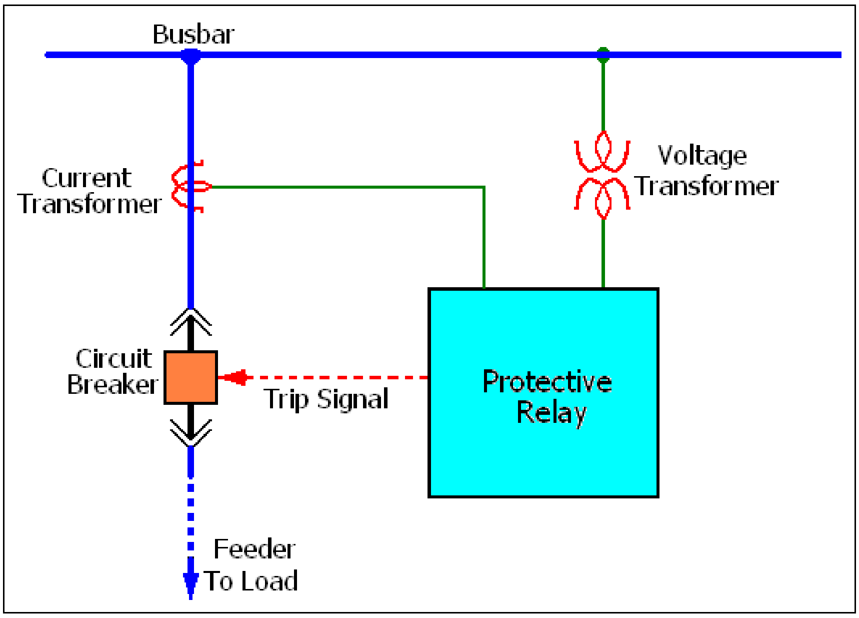


Fig. 4.1-9 Power System Protection

The purpose of protective relaying includes the following:

- To sound an alarm and / or to close the trip circuit of Circuit Breaker so as to disconnect a component during an abnormal condition, which include **over-load, under-voltage, temperature rise, unbalanced load, reverse power, under-frequency, short circuit,** etc.

- **To disconnect the abnormally operating part** so as **to prevent the subsequent faults**, e.g., over-load protection of a machine protects the machine and prevents insulation failure.
- **To disconnect the faulty part quickly** so as **to minimize the damage to the faulty part**, e.g. if a machine is disconnected immediately after a winding fault, only a few of coil windings may need replacement. If the fault is sustained, entire winding may get damaged and the machine may be beyond repair.
- To **localize the effect of fault by disconnecting the faulty part** from the healthy part, causing least disturbance to the healthy system.
- To disconnect the faulty part quickly so as to improve the system stability, service continuity and system performance. Transient stability can be improved by means of improved protective relaying.

Faults cannot be avoided completely, but can be minimized. Protective relaying plays as important role in minimizing the faults and also in minimizing the damage in the event of faults.

PRIMARY AND BACKUP PROTECTION

Primary Protection (main protection) is the essential protection provided for protecting an equipment/machine. As a precautionary measure, an additional protection is normally provided and is called 'Backup Protection'. The Primary Protection is the first to act and the Backup Protection is the next in the line of defense - meaning, if primary protection fails, the backup protection comes into action and removes the faulty part from the power system.

If due to some reason, the main protection fails, the back-up protection serves the purpose of protection. Main protection can fail due to a defect in one of the components in the protective system such as relay, auxiliary relay, Current Transformer **(CT)**, Potential Transformer **(PT)**, trip circuit, Circuit Breaker **(CB)**. If

the primary protection fails, there must be an additional protection or otherwise the fault may remain uncleared, resulting in a disaster.

PROTECTIVE ZONES

The protective relaying of a power system is planned along with the system design. The Circuit Breakers are located at appropriate points such that any component of the power system can be disconnected for usual operation and maintenance requirements and also during abnormal conditions such as short circuits.

Depending upon the rating of the machine, its location, relative importance, probability of faults and abnormal conditions, etc, each power system component (generator, transformer, transmission lines, bus-bar, cables, capacitors, individual loads, etc) is covered by a Protective Zone. A part of the system protected by a certain protective scheme is called Protective Zone or Zone of Protection. Several Protective Zones cover the entire power system and no part of the system is left unprotected (Fig. 4.1-10).

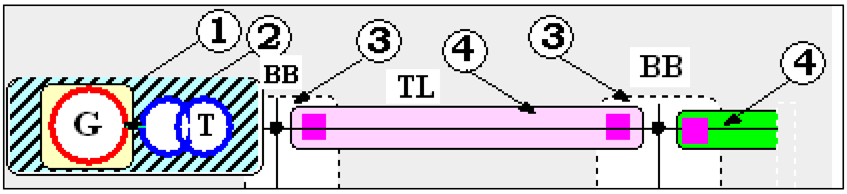


Fig. 4.1-10 Protective Zones

BOUNDARY OF PROTECTIVE ZONES DECIDED BY LOCATION OF CT'S

- Generator protective zone (1)
- Generator transformer unit protective zone (2)
- Bus bar protective zone (3)
- Transmission Line protective zone (4)

SUMMARY

- The purpose of any electrical power system is to generate electricity or (electrical power) and to transfer it from the source to the user.
- A Power Plant is a source of electrical power generation.
- The transmission lines and switchgear connect the source and user.
- The Generating Set includes both the turbine and generator.
- SEC high voltage transmission lines include 380 kV, 230 kV, 115 kV and 69 kV.
- Whenever an abnormal condition develops the protective relay closes the contacts to trip the circuit breaker.
- The other important components in the protective relaying scheme include protective current transformers, protective relays, time-delay relays, auxiliary relays, secondary circuits, trip circuits, auxiliaries and accessories**.**
- Faults can be minimized by improved system design, improved quality of components, better and adequate protective relaying, better operation and maintenance.
- Power system components include generator, transformer, transmission lines, bus-bar, cables, capacitors and individual loads.

FORMULAS

1H.P. = 746 Watts

1MW = 10^6 Watts

GLOSSARY

Prime Mover	Generator Driver that may be driven by gas or steam
Adequate	Enough
MW	Mega-Watts
HP	Horse Power
HV	High Voltage
G	Generator
T	Transformer
TL	Transmission Line
CT	Current Transformer
PT	Potential Transformer
CB	Circuit Breaker

REVIEW EXERCISE

Fill in blanks

1. The _________________ and switchgear connect the source and user.
2. A turbine is a ___________ that may be driven by gas or steam.
3. The protective relaying senses the ____________ conditions in a part of the power system and gives a/an _______ or ________________ that part from the power system
4. A part of the power system protected by a certain protective scheme is called ____.

Fill in blanks for correct answer

3. A generator having a rated output of 100 MW maximum requires a diesel engine or gas turbine rated at ________________ HP to drive it, allowing approximately 10% for energy losses. 1 H. P. of mechanical energy equals 746 Watts of electrical energy.

   a. - 155,000   b. - 147,500

   c. - 157,500   d. - 137500

2. Check True for the correct sentence and False for the wrong sentence:

	TRUE	FALSE
a. - Transmitting power over long distances is wasteful and expensive and is avoided as much as possible, but is still needed.		
b. - During abnormal conditions, the current from the battery supply flows in the trip-coil of the circuit breaker in series with the protective relay contacts, the circuit breaker opens and the faulty part is disconnected from the supply.		

3. Given the power plants a, b, c, g and d in Fig. 1-11, determine the electrical power required by the load areas A, B, C, F and D, assuming generator sets c and g not running.

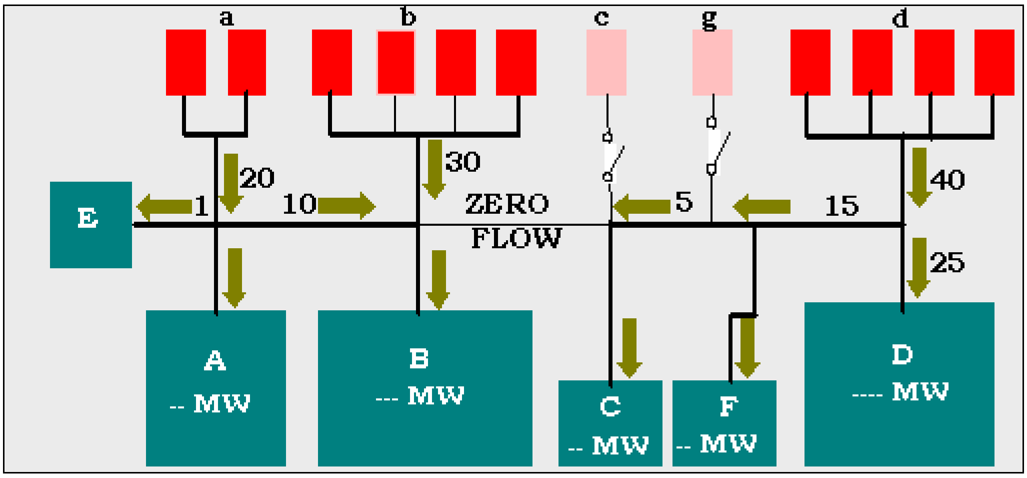


Fig. 1-11 Suitable Power Plants supplying Power to Load Areas

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POWER SYSTEM PROTECTION AND CONTROL

STAGE 1D- BSP102

Textbook/Workbook

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